Power Measurement Lab

Power measurement lab

Microwave measurements

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Power Sensor HP8481A basic specifications

- The HP8481A is general purpose power sensor, here are some of the specs
- 10MHz - 18GHz frequency range
- 1mW to 100mW power measurement range (-30dBm - 20dBm)
- Maximum power 300mW continuous, 15W peak (30W/msec pulse)
- N male; 50 ohm connector.
- VSWR <= 1.10:1 50MHz - 2GHz

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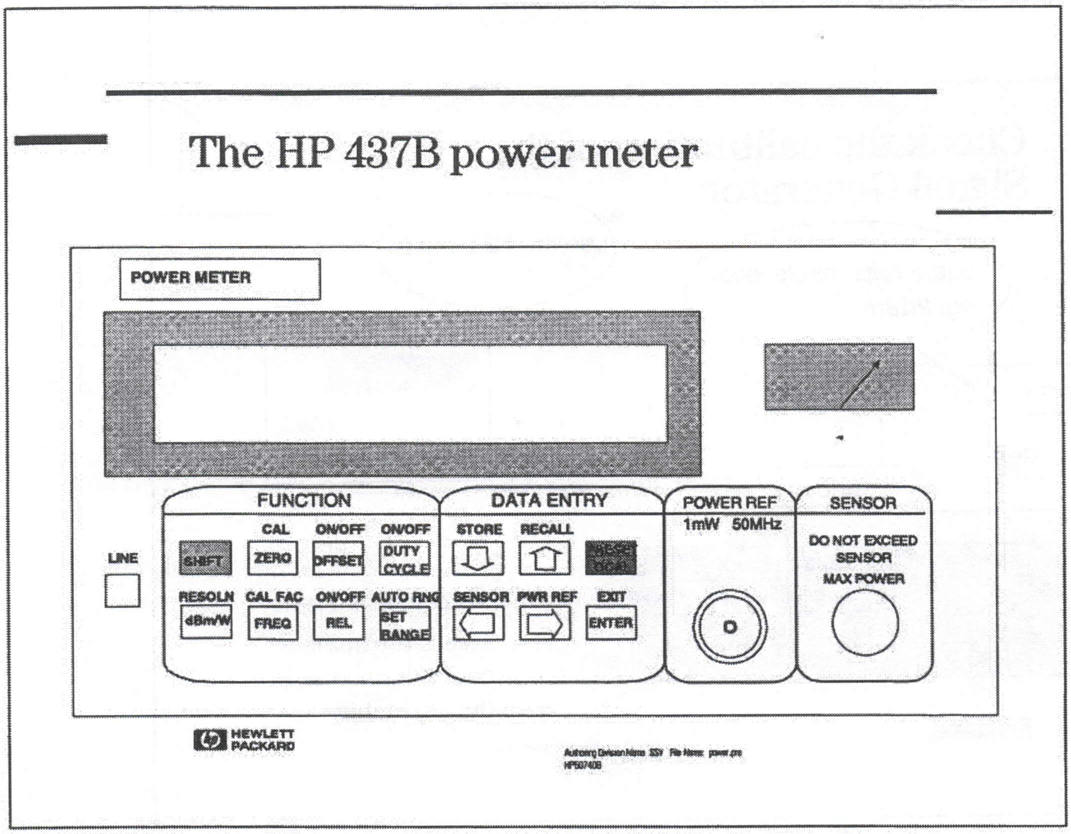
In this lab we shall use the HP8481A thermocouple power sensor. Here are some specifications.



Since we shall be measuring below 1GHz no attempt will be made to use a calibration factor other than 100%.
Before measuring the the output power flatness of the Sig Gen. we must calibrate our power meter and power sensor.
The power meter is smart and will turn on and off the power ref. appropriatly during a calibrate and zero cycle. You can toggle this source on and off independantly of this.

PRESET the power meter.

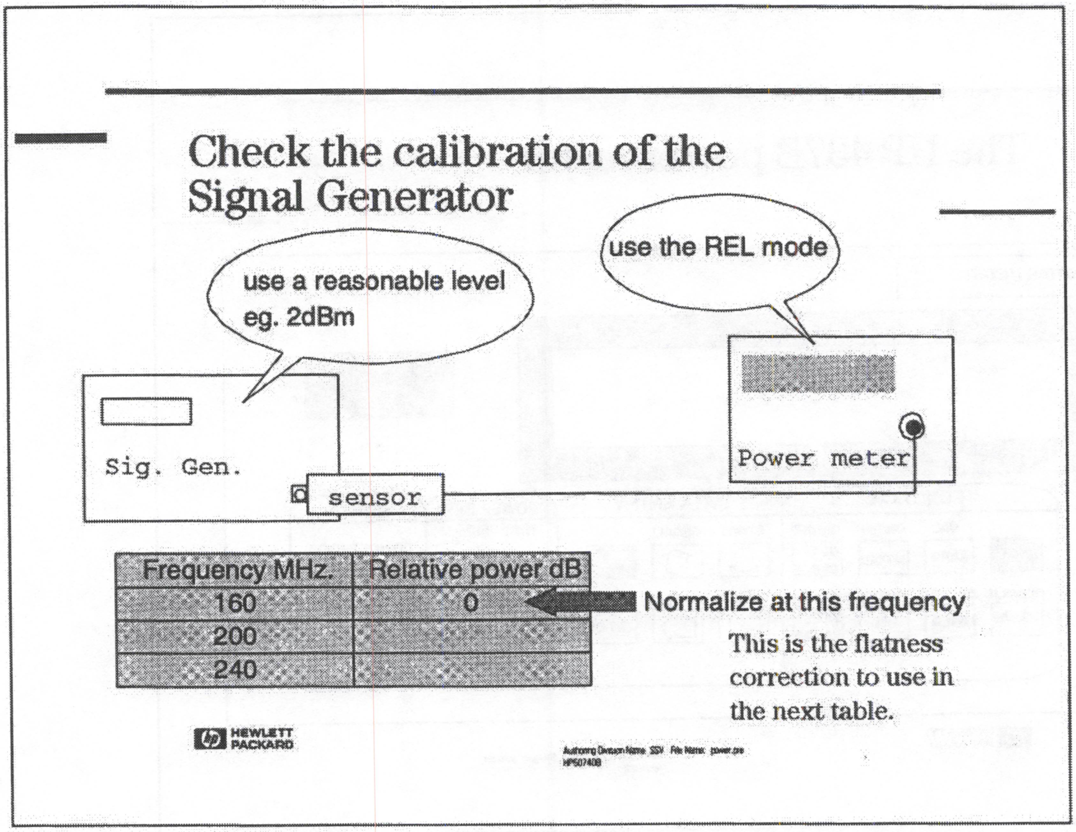
Connect the power sensor to the Power Reference output port.

ZERO the power meter. press

CALIBRATE the power meter. press

Ref calibration factor should be 100% adjust if necessary, press ENTER.

Turn ON the Power Reference with the sensor still connected. Is the reading 1.0mW or 0dBm? If not try the above procedure again or ask the instuctor for help.
Before proceding with the measurement toggle the dBm/mW key to get a reading in dB.



Signal Generator Flatness

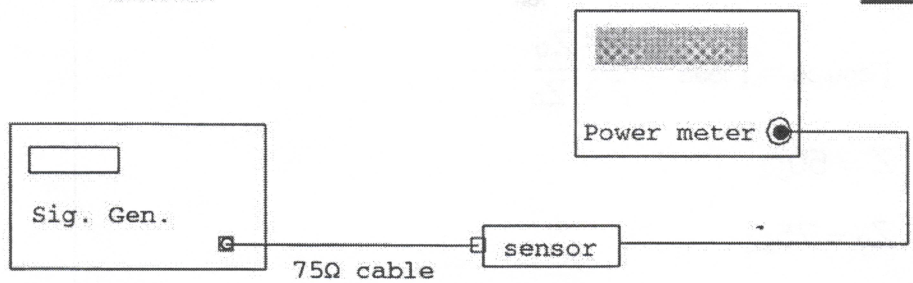
One of the specifications of a signal generator is the uncertainty of the output power setting. This is important because a signal generator is often used as a standard in making measurements related to power. For example, receiver sensitivity measurements depend on the calibration of the input signal level and the associated uncertainties.

Choose any reasonable power avoid 0dBm to see how REL works.

Use REL mode on power meter, this will normalize measurements to the 160MHz. fill in the table above.

Note: The power meter is used to calibrate the signal generator, the display of power on the signal generator is a display of some secondary effect, but NOT a power measurement.

Measure the insertion loss of one cable



Frequency MHz.	160	200	240
Measured Loss dB. Loss			
Flatness Correction dB Corr	0		
Corrected loss dB. Loss – Corr			

Maintian the same REL state of the power meter and measure the loss of the cable;just one cable. Correct the reading by the correction values from the Sig. Gen. calibration step.

Calculate the source and load mismatch

$$\Gamma\text{source} = \Gamma\text{load} = \frac{Z - Z_o}{Z + Z_o}$$

$Z = 50\Omega$

$Z_o = 75\Omega$

$\rho = |\Gamma|$

$$\text{SWR} = \frac{1 + \rho}{1 - \rho}$$

SWR of Source	
SWR of Load	

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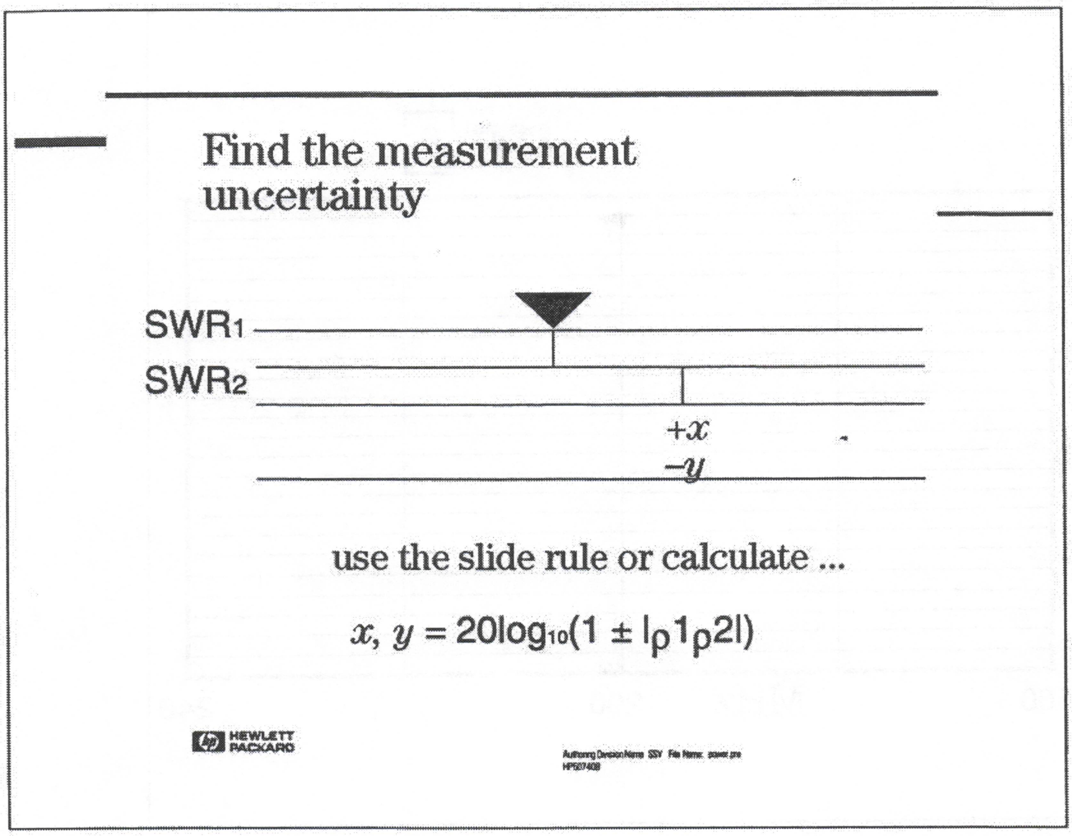
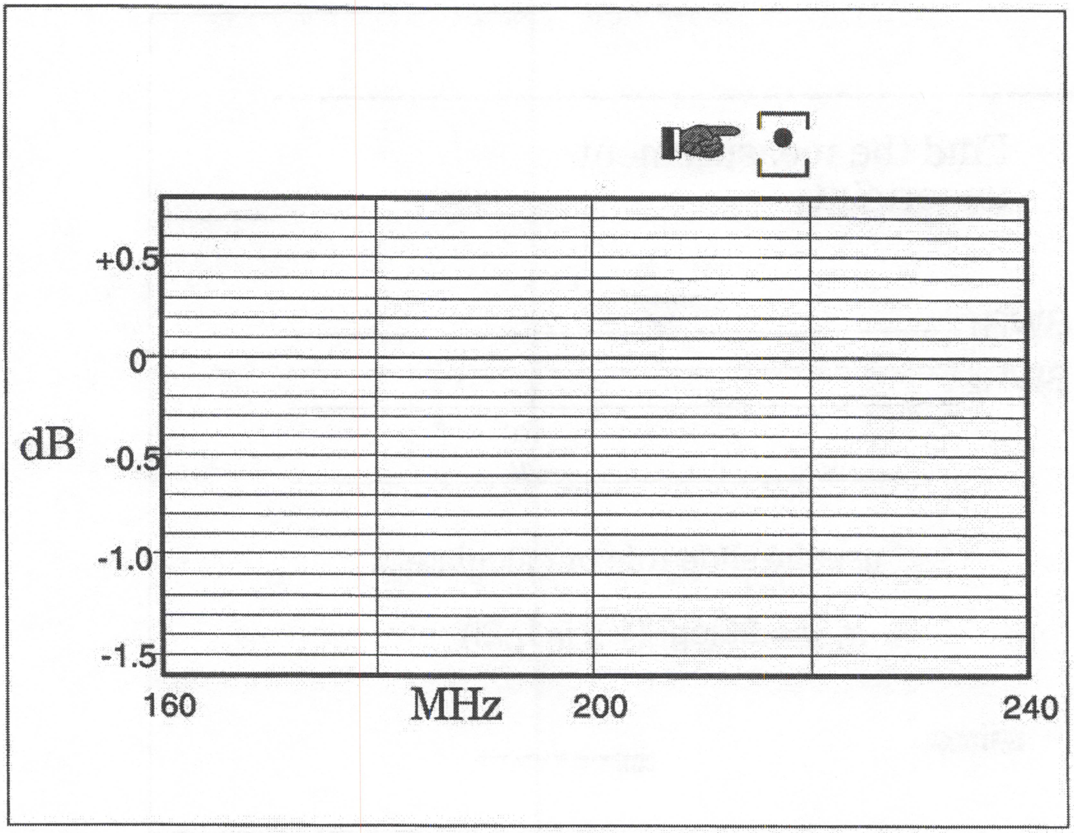
We shall use the "Mismatch Error Limits" side of the reflectometer calculator to estimate the uncertainty of the measurement. So we need to convert rho to SWR first either by calculation or by using the front side of the calculator.



x and y are not equal but the differences for our lab will be about 0.01dB. So we can say our measurement is:

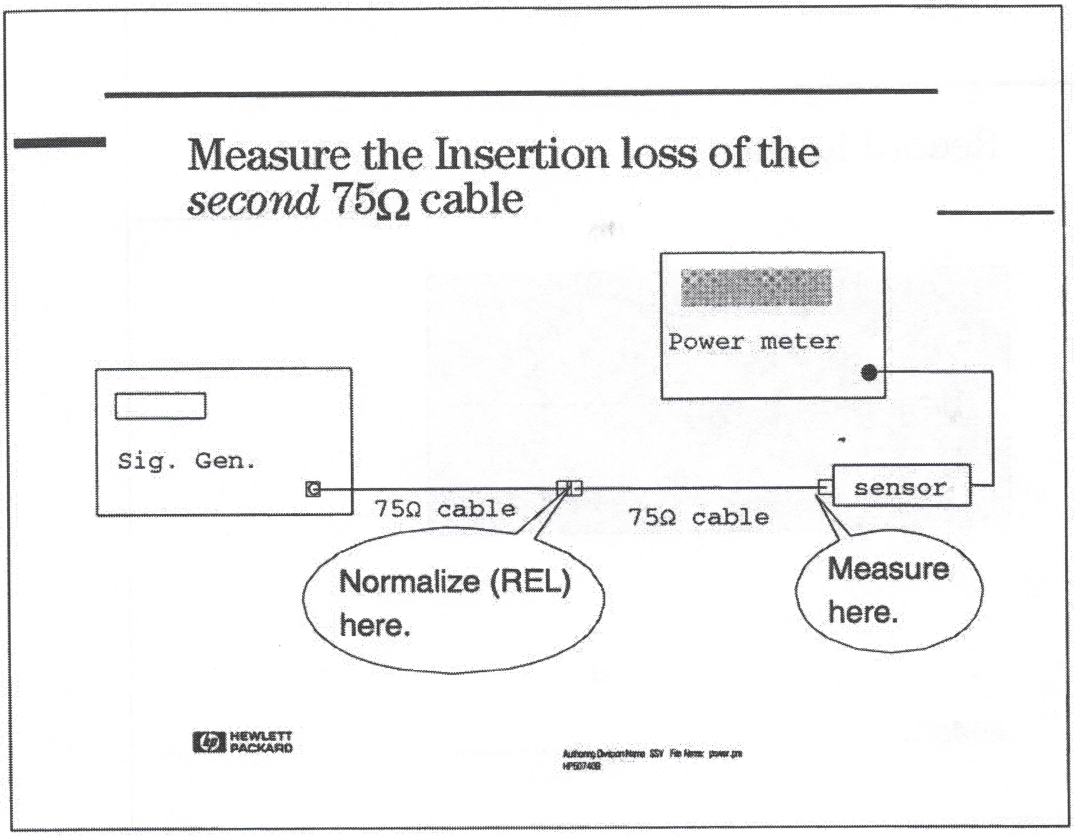
M± x dB



Plot the points and put brackets around the points to show the uncertainty range.

See above

Is the mismatch uncertainty a large part of the measured value?



Normalize the power reading from one cable. Then attach the other cable with the "bullet" f-f BNC adapter. Although this item is 50Ω we shall ignore this for this lab. The frequencies are different from the original measurement, see the table on the next page.

Record Results

FREQUENCY	INSERTION LOSS OF CABLE
60MHz	
44MHz	
38MHZ	

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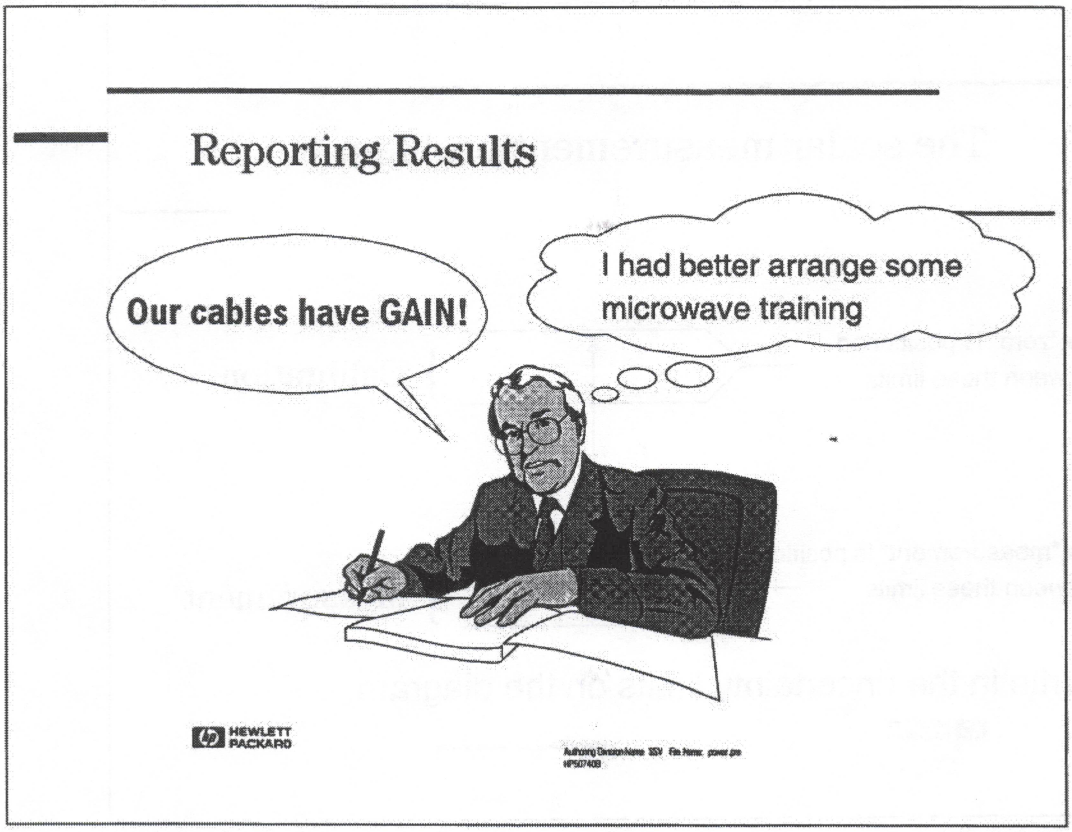
The accuracy of a power measurement is degraded by reflections between the sensor and the source. We have contrived this lab to emphasize:
The need to control reflections
The need to associate an uncertainty to a measurement

If we are given the task to measure some 75Ω cable using 50Ω test equipment what kind of results can we expect?

Our source is the RF signal generator with one 75Ω cable attached
The device to test is the second 75Ω cable
Calibrate the system at the end of the first cable

set sig gen to a nominal power output eg. 0dBm at 100 MHz
use REL feature to normalize power reading to 0dB.

Connect the second cable to the end of the first cable using a BNC "bullet"
Measure the insertion loss of the cable
Repeat at all the frequencies.


Reporting Results
Our cables have GAIN!
I had better arrange some microwave training
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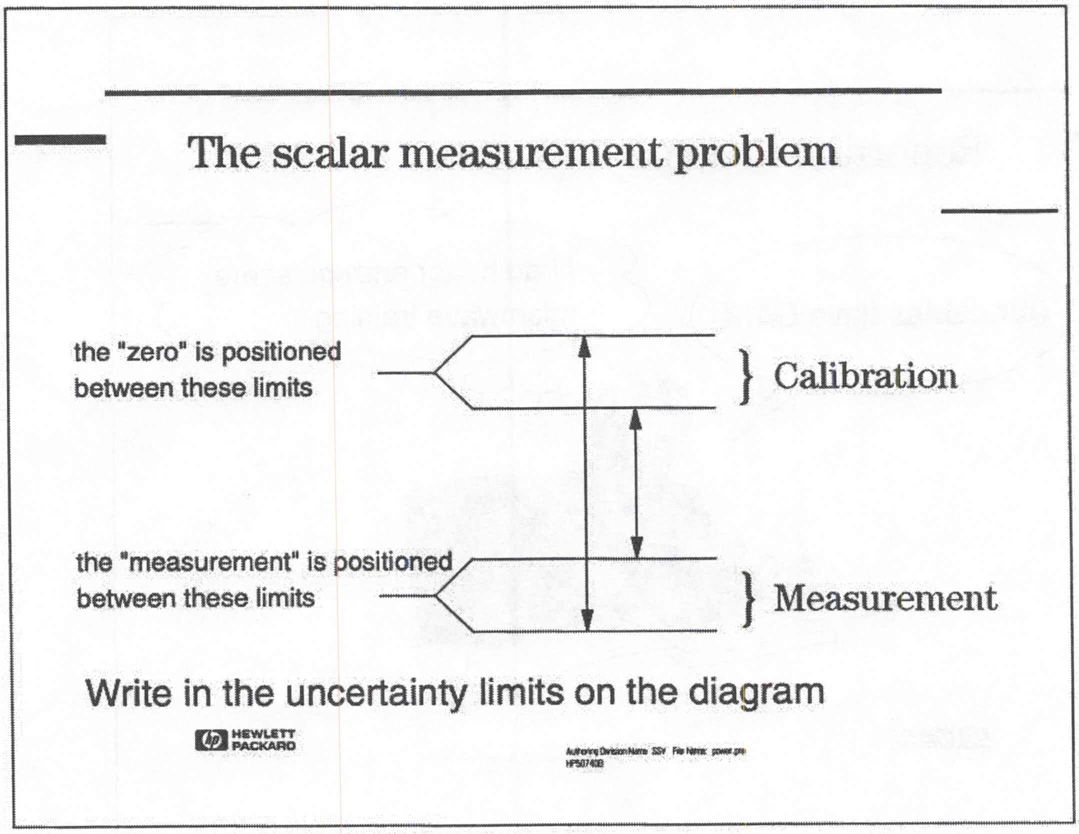
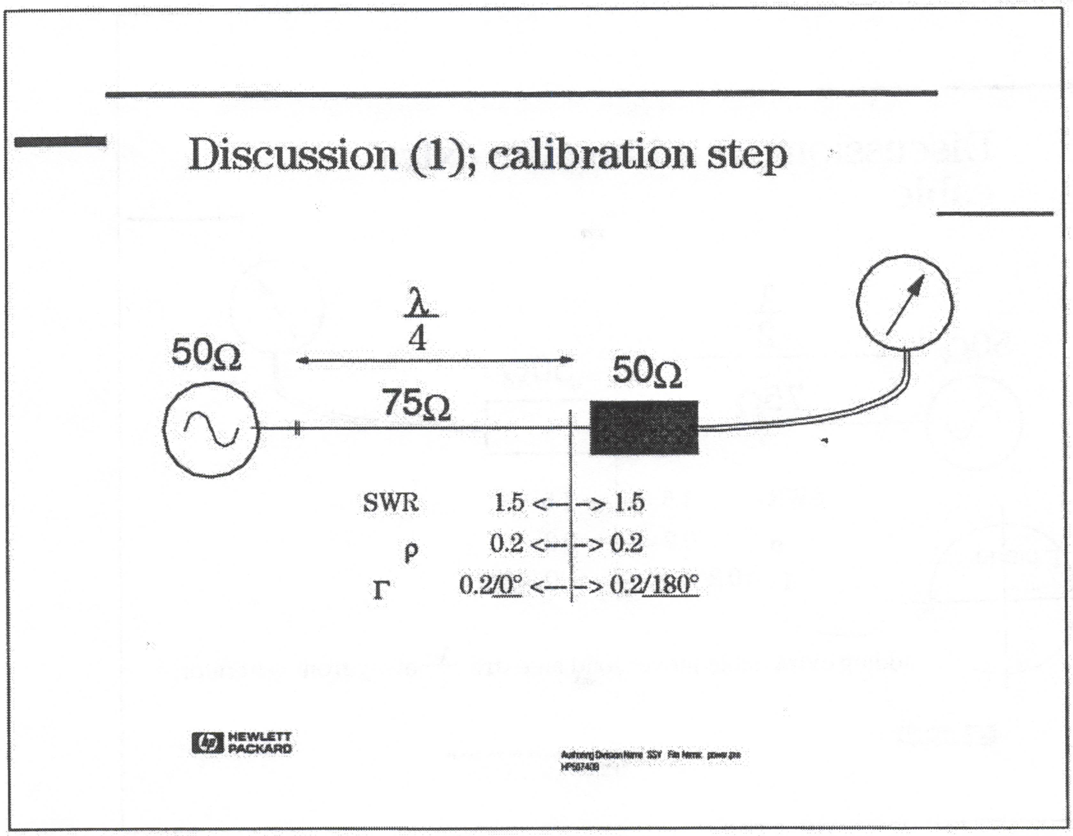


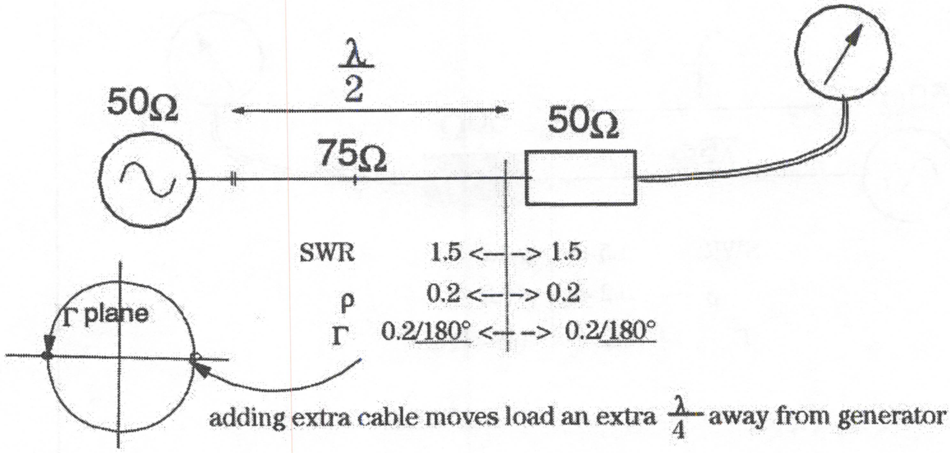
Both the calibration and measurement are subject to an uncertainty because the phase of the reflection coefficient is unknown and different between the two steps.

We set up this lab to demonstrate a point, that it is possible to measure a gain for a device that should have loss. How did we manage this? Well frequencies were chosen such that during the cal stage Γload was 180deg different to Γgen; power measured was pessimistic.
During the measurement stage âload was in phase with Γgen; power measured was optimistic.



In the Gamma plane (Smith chart) the Γ(source) = 0.2 and Γ(load) = - 0.2

Discussion (2); adding the extra cable



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Now Γ(source) has changed angle and is -0.2.

Discussion (3); calibration (pressing REL)

Calibration stage

Z_0 Mismatch loss = $10\log|1 - \Gamma_g\Gamma_l|^2 - 10\log(1 - |\Gamma_l|^2)$

This part is the "mismatch uncertainty".

This part is the "mismatch loss".

if $\Gamma_g\Gamma_l = -x$ then ...

Z_0 Mismatch loss = $10\log|1 + x|^2 - 10\log(1 - |\Gamma_l|^2)$

Power Meter Normalized on the low side.

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Authoring Division Name SSY File Name: power.pre
HP50740B

The sign of this part of the mismatch loss being a positive quantity means there was a situation where less power than to a Zo load (75Ω) was transferred to the power sensor.

Discussion (4); measurement and conclusions.

Measurement Stage

if $\Gamma_g \Gamma_l = +x$ then ...

Zo Mismatch loss = $10\log|1 - x|^2 - 10\log(1 - |\Gamma_l|^2)$

Power Meter Measurement on the high side.

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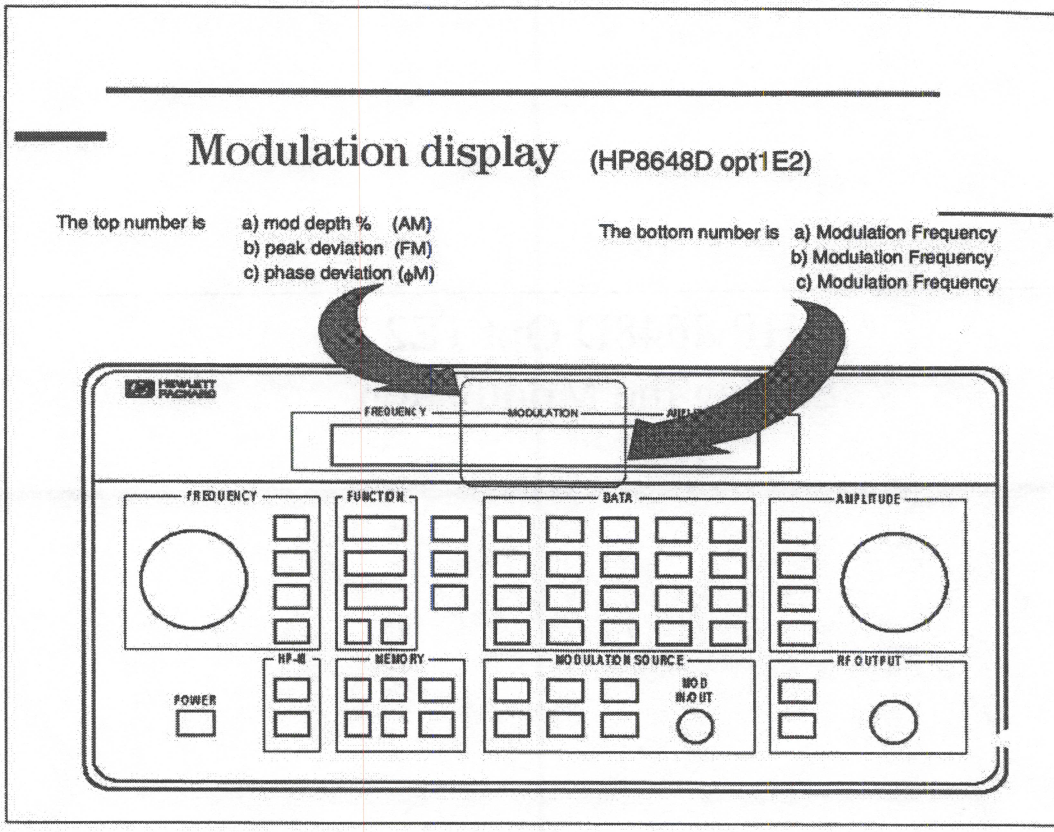
HP50740B

The sign of this part of the mismatch loss being a negative quantity means there was a "gain". well not really gain but because Γ(source) is now -0.2 the power transferred to the power sensor was more than there would be to a Zo (75Ω) load.

We did not know this information during the measurements so in the uncertainty calculation, or using the slide rule only the scalar value was known so rho is used instead of â in the calculation $U = 10\log|1 \pm \rho_L \cdot \rho_G|^2$

HP 8648D Opt.1E2
Setting the Modulation



To set the Signal Generator to a known state:

Preset the HP 8648D as follows:

1. Turn RF OUTPUT off (press RF OUTPUT [RF ON/OFF] button so "RF OFF" is in the display).
2. Turn modulation off (press FUNCTION [AM] MODULATION SOURCE [INT 1 kHz] then [MOD ON/OFF]

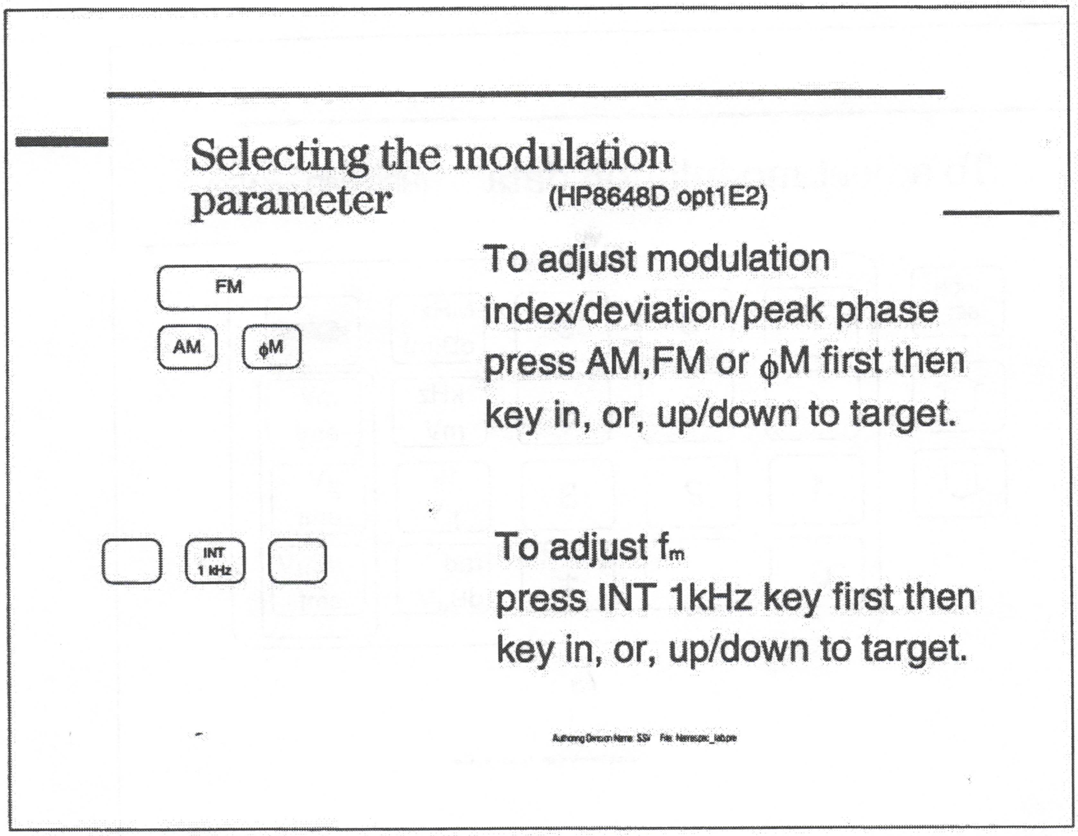
Make sure amplitude and frequency ref. mode is OFF

3. Turn reference mode off (press FREQUENCY [REF SET] so "0 MHz" is in the display. Then, press FREQUENCY [REF ON/OFF] so a non-zero value (MHz) is in the display).
4. Repeat Step 3 for the AMPLITUDE function.

The upper part of the display shows the modulation amplitude quantity, index, deviation or phase deviation corrosponding to the selected type of modulation.
The lower display shows the modulating frequency:

400 Hz (fixed)
1kHz (fixed) or
SIN/ SQUARE/ SAW/ RAMP, all variable from 0.01 kHz to 20 kHz.

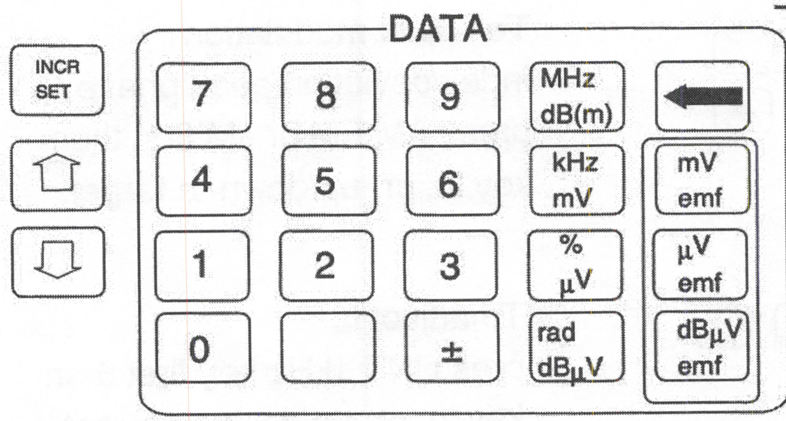
These are selected by cycling the 1kHz button,(if you miss just cycle through till you find it.)



The 1kHz key allows selection of the internal source states.

Pressing this key may select the next state, If you inadvertantly go to an unwanted state just keep pressing the key until the display indicates the wanted state.

To adjust modulation data (HP8648D opt1E2)



If *modulation type* is active then the keypad will adjust the mod index, frequency deviation or phase deviation.

If *modulation frequency* is active then the keypad will adjust the frequency.

The INCR SET may be used independantly for all the states, that is: mod index, freq dev, phase dev. modulating frequency.

PART 1: Amplitude Modulation (A.M.)

I. In this part we shall look at amplitude modulation (AM) signals generated by a signal generator on the spectrum analyzer display.

A. The signal generator provided will have internal and external modulation capability.

1. Write below the *internal fixed* modulation rates provided.

Internal modulation frequencies	
F1	38 K Mhz
F2	10 KHZ

Your signal generator may have an *internal variable* modulation source, check it out and select a modulation frequency 5kHz or greater.

B. The Spectrum Analyzer has many keys etc., we shall only be using the Basic Spectrum Analyzer controls* to adjust our window into the frequency domain and maybe adjust oudisplayed signals on the screen.

1. Write below the analyzer model number and frequency range.
2. What is the maximum input power and any other limitations, write them below.

SPECTRUM ANALYZER DATA				
MODEL #	8549E			
FREQ	Max	2,9GHz	Min	9KHz
Max input power	+30 dBm 1 Watt			
Max voltage	Ø VDC			

C. Spend time getting used to the Signal Generator controls, for example:

1. Center Frequency
2. Output level
3. Modulation control

D. Set up Sig Gen. and the Analyzer.

(Experienced users please hold back to allow less experienced students to find the signal by using the basic controls)

1. Connect up the analyzer and signal generator.
2. Select a suitable frequency and power level on the Sig Gen, say 100MHz and 0dBm.
3. Write down the chosen frequency and power output level.
   i. Frequency = 100 MHz
   ii. Level = ∅ db
4. Can you find the signal on the spectrum analyzer? Use the spectrum analyzer controls mentioned above (1.B) to center the signal on the CRT.
5. Adjust Ref level so that the top of the displayed signal just grazes the top horizontal graticule line.
6. Write down the spectrum analyzer center frequency and the Reference Level.
   i. Center Frequency = 100 MHz
   ii. Reference Level = 5 10 DBM (1,2)
7. The values in (3) and (6) had better be close!

Check which level is correct	
level 3ii	dBm
level 6ii	∅ 2 dBm

E. Set up amplitude modulation and make some measurements.

1. Set up the analyzer :
   i. CENTER FREQ. = frequency of the Sig Gen
   ii. SPAN = about 10 times modulation rate
2. Use the Sig. Gen. modulation control to vary the modulation level from 0 to 100%. As you do this....
   i. Do the sidebands change in amplitude? Y
   ii. Does the carrier change in amplitude? N
   iii. Does the **total power** in an AM system depend on the modulation level? yes ~~X~~ or no X
   iv. At high mod levels, how many signals can you count on the display? ALOT

Remember with pure sinusoidal modulation we would only expect 3 signals, the carrier and two sidebands, you probably counted more! See box.

v. Discuss with your group and note the possible reasons for this.

____
____
____

A.M. FORMULA:

For a sinusoidal carrier with a sinusoidal modulating signal the equation is:

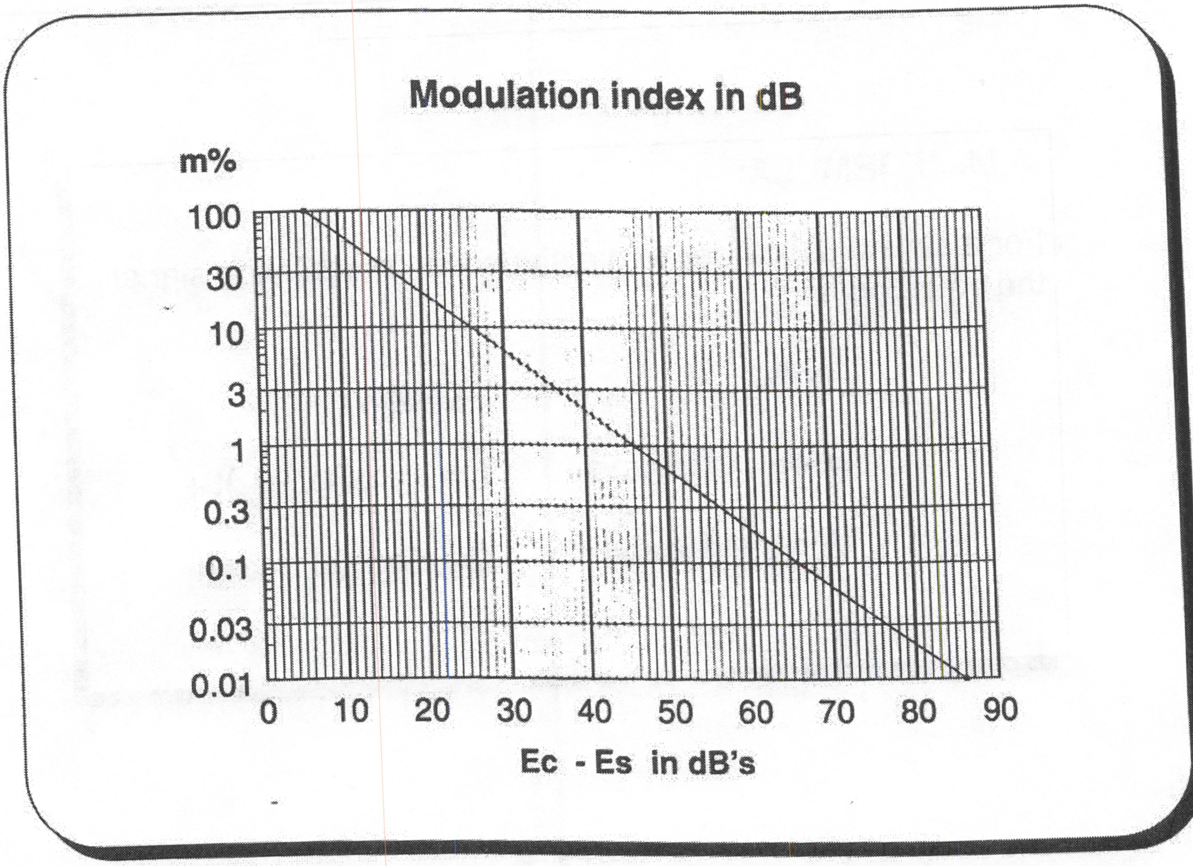
Carrier	$\cos(\omega_c t) +$
Lower sideband	$(m/2)\cos(\omega_c - \omega_m)t +$
Upper sideband	$(m/2)\cos(\omega_c + \omega_m)t$

3. Adjust the mod level control so that the first pair of modulation sidebands are 26dB below the carrier. What is the modulation index expressed as a percentage?
   i. From the graph ___10___
   ii. From the Sig Gen ___~~8~~ 10___
   iii. From the formula ______

Thes should all agree within a few percent!

4. Can you adjust the Sig Gen mod. level to achieve 1% modulation?
5. What modulation percentage would corrospond to:
   i. -6dBc (dB below carrier) ___100___
   ii. -12dBc ___50___
   iii. -18dBc ___25___
   iv. -46dBc ___1___
6. Change to another modulation frequency, do the sideband amplitudes change?

7. Check the frequency difference between the carrier and sidebands, is this a measure of the modulation rate?



This graph will help you estimate the mod index from sideband difference or vice versa. The exact formula is:-

$$m(dB) = -[E_c(dB) - E_{sb}(dB) - 6]$$

For example, if Ec - Esb = 27dB then

$$m = -(27 - 6)dB$$

$$= -21dB.$$

In linear terms $m = 10 \exp(-21/20)$

$$= 10^{-1.05}$$

$$= .089 \text{ or } 8.9\%$$

Mod index and Sideband table

	(Ec - Esb) dB	m%
Full modulation	6	100.0
	12	50.0
	18	25.0
	26	10.0
	32	5.0
	46	1.0
	52	0.5
Still visible on Spec. An.	66	0.1

Part 2: Angle Modulation (FM & PM)

In this part we shall observe FM and PM signals generated by a signal generator on the spectrum analyzer.

In part 1 you wrote down the internal modulation frequencies available in the signal generator, for quick reference note them down here.

Internal modulation frequencies	
F1	
F2	

- Set up the Signal Generator and analyzer as in the AM lab.
- Select a modulation rate.
- Make sure that FM is active.
- Start with 0 Hz peak deviation and slowly increase while observing the center frequency and the modulation sidebands displayed on the analyzer.

Does it seem reasonable that the total power in an FM signal remains constant? Yes X No___

The amplitude of the response at the center frequency and and sidebands should change. Find the point at which the center frequency response is smallest. Our deviation control will not be fine enough to make this disappear completely.

This precise datum is used to calibrete FM transmitters to FCC specifications, it is called the **"Bessel Null"** method. We know from mathematical analysis where all the nulls occur. If we have done the adjustment properly we have found the "first Bessel null" which occurs when the ratio $\Delta f/f_m$ = about 2.4

-9
20

18 2.4
V

Bessel Null Calculation	
Modulation Frequency f_m	1KHz
Peak deviation from Sig. Gen. Δf	2.4
$\beta = \Delta f/f_m$	
Calculate Δf: assume $\beta = 2.4$	

-29
18

Angle Modulation
(F.M & P.M)

- Try this for another modulating frequency :

Bessel Null Calculation	
Modulation Frequency f_{m2}	~~18~~ 7.7
Peak deviation from Sig. Gen. Δf	18
$\beta = \Delta f / f_{m2}$	2.33
Calculate Δf: assume $\beta = 2.4$	

In each case the deviation calculated will probably differ from the indication on the signal generator.

- In which one would you have most confidance ?

Confidence in deviation measurement	
The Signal Generator	
The Calculation	X

- 1) Reduce the deviation until you see just two significant sidebands. Observe that the spectrum analyzer shows what could be AM. A swept spectrum analyzer does not "know" the relative phases of the displayed signals.

  A significant sideband is one which is > -40dBc

What is the occupied spectrum bandwidth?	5KHz

- 2) Increase the deviation to a very large value, notice how the spectrum does not (easily) provide information about the deviation .

What is the occupied spectrum bandwidth?	

Now you can see why this is sometimes called non-linear or exponential modulation. There is no easy, straight line, relationship between, the input variables Δf and f_m ,and the output spectrum. Even with a sinusoidal modulating signal the spectrum is complicated. There is however a rough "rule of thumb" known as **Carson's Rule** which allows an estimate of spectral occupancy

$$\mathbf{BW \approx 2(\Delta f + f_m)}$$

Check it out with some measurements.

A significant sideband is one which is > -40dBc

- Use the values from 1) and 2)

$2\times(\Delta f + f_m)$

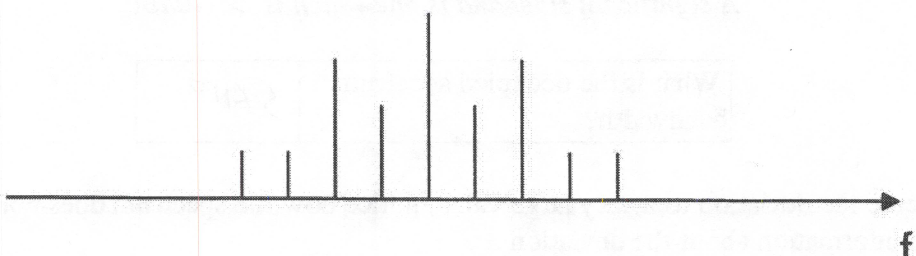
CARSON'S RULE, How good is the approximation.		
	From S/A	Calculated
Case 1 (small β)	40 KHz	30 KHz
Case 2 (large β)	120KHz	124 KHz
Case 3 medium β	~~300KHz~~ 250KHz	180

$2\cdot(20+60)$

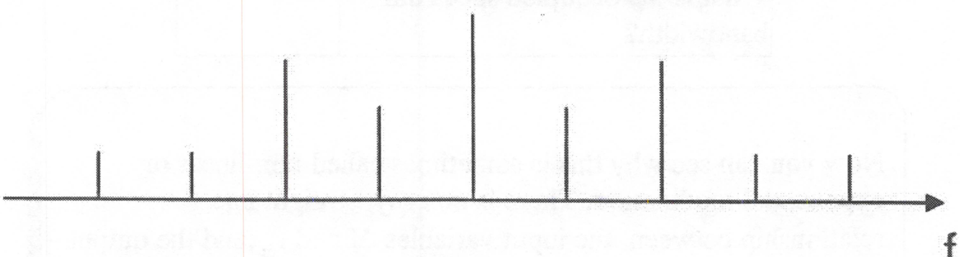
Phase Modulation

In FM the angle of the center frequency can change by many revolutions, in PM the angle must be constrained within ±180°. If f_m is changed then the 'incidental' deviation is changed at the same time maintaining β constant. The term incidental I used to describe that any frequency deviation is incidental to the phase modulation process, but is not an independant variable. In fact β becomes the phase constant of the modulation.

- Use the **phase** modulation function on the signal generator to observe carefully that only the frequency spacing of the sidebands changes when f_m is changed



Phase or Frequency modulation?



PHASE MODULATION doubling the modulating frequency.

Angle Modulation (F.M & P.M)

Vector network lab.

Microwave measurements

Vector Network Lab

Vector Network Analyzer Lab.

PART 1: SET UP AND CALIBRATION

In this section we will take a look at how to set up a measurement for the HP8753- Vector Network Analyzer. We will also perform a simple Reflection and Transmission Calibration.

POWER LEVEL

The S Parameters of some devices such as transistors and other active devices are sensitive to level of incident power, i.e. the Sparameters change with level. In most cases however including most passive devices, which are linear over a very wide range, the parameters dont change significantly with incident power level. We will be testing a band pass filter, and the choice of a high power level is to facilitate measurements over a wide dynamic range.

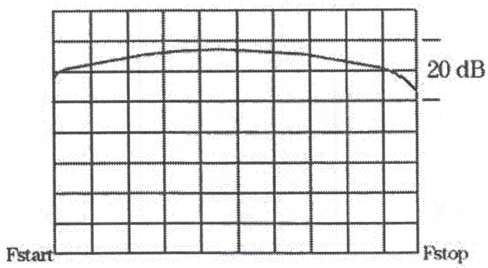
1) Preset the instrument.
2) Set the power output to 0 dBm.

Vector Network Analyzer Lab.

SOURCE

We will eventually need to set START/STOP or CENTER/SPAN frequency controls. Discover wherethe bandpass of the filter is by looking at a full range response in the S21 mode. Remember the display is scanning to over 3/ 6GHz. but the response may be scrunched up in the first 100MHz. Use the Stop Freq control todecrease the Stop Freq. explore the displayed response till you find the passband.

Set Fstart and Fstop to convenient numbers so as to view the passband of the filter with about 10 - 20dB of the skirts.



Note on VNA channels:

The channels you may wish to allocate are Measurement channels, they have (unlike an oscilloscope) nothing to do with the inputs labelled port1 and port2. For example you may wish to view the measurement results of s_{11} and s_{21} . If s_{11} is set up on channel 1 and s_{21} on channel 2 then pressing the channel button will enable sequential viewing of the measurement displays. Or if split display is selected then one can view both measurements at the same time.

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Vector Network Lab

Calibration Types & Errors they Minimize

	Freq. Response: Refl/Trans	Mismatch: Source/Load	Leakages: Directivity/ Isolation
• Frequency Response	X		
• 1-Port	X	X	X
• Full 2-Port	XX	XX	XX

Every calibration leaves some residual error. Calibration reduces the error's magnitude and thus improves the accuracy of your measurements.

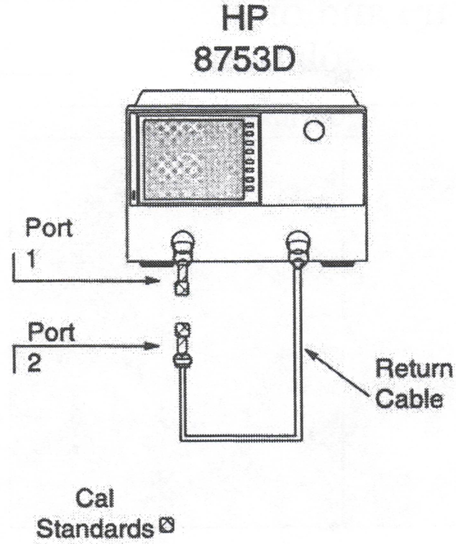
NO CALIBRATION will allow a quick look at the DUT to set up required frequency range.

RESPONSE CALIBRATION is the fastest but least comprehensive calibration type. It requires only a single calibration standard (short, open, thru), but corrects only reflection or transmission frequency response error.

1-PORT CALIBRATION gives the best accuracy for 1-port measurements correcting all three systematic errors for either port 1 or port 2.

2-PORT CALIBRATION requires the most connections but measures and removes the 12 systematic errors for both the forward and reverse directions.

2-Port CAL: Reflection



If you are connecting the DUT between port 1 and port 2 as shown above, then you must perform the reflection calibration at these planes. Port 1 is the network analyzer's test port but port 2 is at the end of the test port return cable. To measure reflections at each port (S11 for port 1 and S22 for port 2), connect an open, short, and a broadband load to each port, pressing the matching softkey after every connection. You can connect the standards in any order since the reflection calibration coefficients are calculated only after measuring all the standards. Disconnect each standard after the network analyzer flashes the message "WAIT MEASURING CAL STANDARD," beeps, and prompts you to connect the next cal standard.

Calibration (Set up and omit isolation)

Instructions	HP 8753D
Look for a hardkey labeled [CAL]. You need to inform the network analyzer that you are using N cal standards from the N Cal Kit.	[CAL] {CAL 7 mm} {CAL 1 N}
Access the Cal menu.	
Select a Full 2-port calibration.	
The softkey menu should display the following options: Reflection, Transmission, and Isolation. You do not need Isolation for this particular measurement. We are not going to examine the filter reject band where a hgh dynamic range > 70 dB is needed.	{FULL 2-PORT} {ISOLATION} {OMIT ISOLATION} {ISOLATION DONE}

Authoring Division Name: SSV File Name VNA_LAB.PRE

Calibration (Open, Short and Loads)

Instructions	HP 8753D
Select the Reflection softkey to show the type of precision standards that need to be connected to port 1 and port 2.	{REFLECT'N}
Connect open. Connect short. Connect broadband load	{OPENS} {OPEN M}, {OPEN F} {DONE OPENS} {SHORTS} ,{SHORT F} {SHORT M}, {DONE SHORTS} {LOAD}

(The (F) &(M) designations refer to the port not the standard)

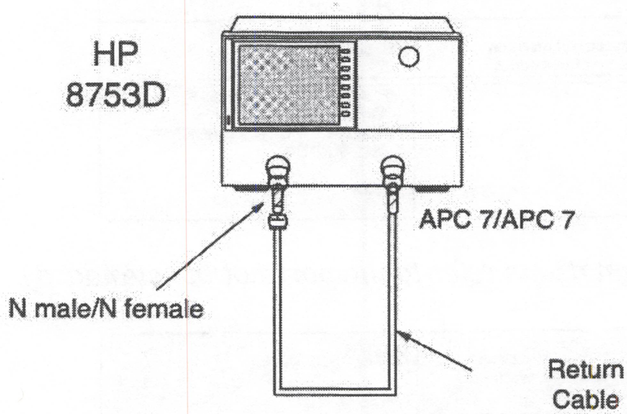
When all the softkeys under S11 and S22 (open, short, and loads) are underlined (meaning that the standards in that class were measured), exit this menu.	{STANDARDS DONE}

When using N shorts and opens, the VNA needs to know which stored model to apply because the OPEN M and OPEN F have different offsets, as do SHORT M and SHORT F.
The softkey butten to press is the port type not that of the standard.

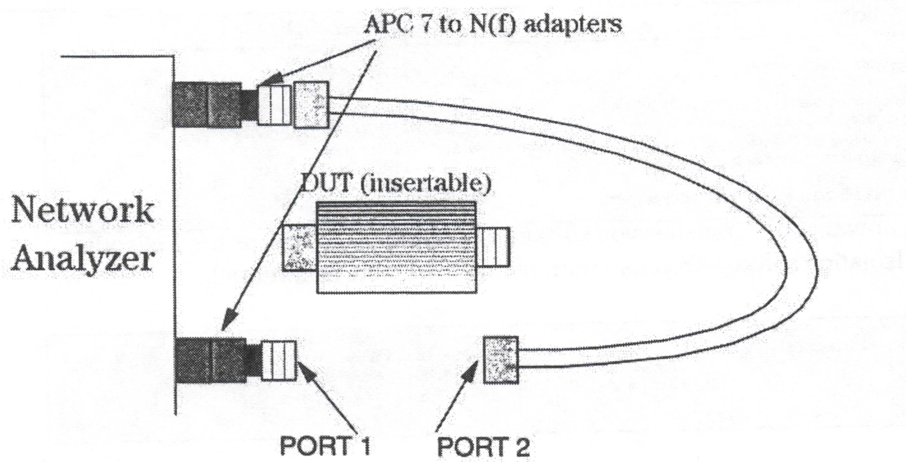
The network analyzer then calculates the reflection calibration coefficients and stores them into internal memory.

Congratulations! You have just completed the most difficult part of the 2-port calibration. The Reflection and Isolation keys should be underlined; now only a simple transmission calibration sequence is left.

2-Port CAL: Transmission



Connection with N - N cable



If the cable supplied is N-N this is the suggested way to organize the connections.

Calibration (Transmission)

Instructions	HP 8720D
Select theTransmission softkey.	{TRANSMISSION}
Since transmission calibration requires a "thru" connection where port 1 is connected directly to port 2, connect the test port return cable (port 2) to port 1. Now select each of the thru softkeys. Note that for each measurement, the network analyzer selects the appropriate S parameter.	{FWD. TRANS. Thru} {FWD. MATCH Thru} {REV. TRANS. Thru} {REV. MATCH Thru}
When all the softkeys are underlined, exit this menu.	{TRANS. DONE}

Note now that the Transmission softkey is underlined as well as the Reflection and Isolation softkeys.You have completed the 2-port calibration!

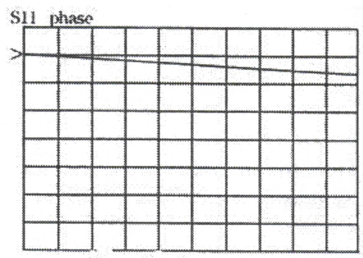
Save the calibration in Cal set 3.	{DONE 2-PORT CAL} {SAVE} {SAVE REG 3} or {RE-SAVE REG 3}

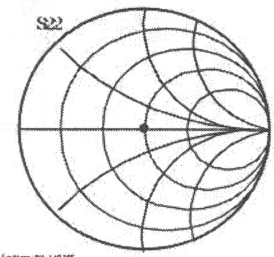
Authoring Division Name: SSV File Name VNA_LAB.PRE

The through connection provides four standards, the softkeys for each standard must be pressed.

Measure the calibration standards

Instructions	HP 8753D
Measure S21 magnitude and phase.	[MEAS] {Trans: FWD S21} [FORMAT] {PHASE}
Now connect an open to see if the reflection coefficient, S11 magnitude, is nearly flat at 0 dB indicating total reflection. Also look at the phase.	[MEAS] {Ref: FWD S11} [FORMAT] {PHASE}





Why wasn't the phase flat at 0 degrees?

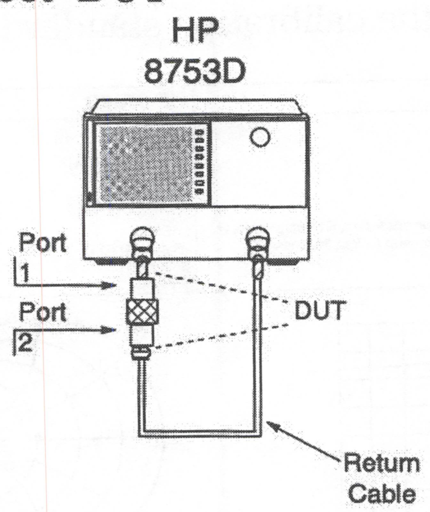
S_{11} phase should vary linearly with frequency since N open cal standards are offset and thus add electrical length and progressivly lagging phase with increase in frequency.

Try all the standards. By putting the broadband load on ports 1 and 2, you can check the stability of your cable. The load will have a high return loss and will be at the center of the Smith chart.

The S_{11} and S_{22} "Smith chart" format should be viewd,
S_{22} with autoscaled display will show a "fuzz" about the center of the magnified chart. Now move the cable, the trace may move a little BUT if it moves a lot and wont return you probably have a bad cable..

Vector Network Lab

Connect DUT



Connect the DUT

The adapters are part of the test set so dont remove them after calibration.

Carefully connect the DUT between port 1 and port 2.

Choose the appropriate format

Right now you should be viewing S11 phase, S11 phase should vary linearly with frequency. Since this is a band pass filter, you should look at S11 and S21 magnitude in log magnitude and polar formats.

Instructions	HP 8753D
The center of the filter will be at X MHz. While viewing S21 log mag on screen, set a MARKER to X MHz and tune the notch to the marker position.	[MEAS] {Trans: FWD S21} [FORMAT] {LOG MAG} [MKR] X [Terminate]

Authoring Division Name: SSV File Name VNA_LAB.PRE

What is the insertion loss, S21, of the filter at X MHz? - 23.04db

What is the return loss at X MHz?

(To see the return loss, switch back to S11 log mag). Are these acceptable values?

- 2.8 db cal

- 3.02 uncal

Marker functions

Instructions	HP 8753D
Reset marker to OFF	[MARKER] (all OFF)
Use some of the marker tools to evaluate the filter. Discover the minimum insertion loss and the 3dB bandwidth.	[MARKER FCTN] {MKR SEARCH} If there was no marker on, one will come on at this stage.
First use marker search to find the min insertion loss of the filter, then use delta marker to find the 3dB points. The marker (1) for example is set to reference The marker 2 is activated, the frequency difference and the dB difference from the ref. is shown on the upper right of the display.	{SEARCH: MAX} [MARKER] {Δ MODE MENU} {Δ REF = 1} {MARKER: 2} Now use the knob to explore the band pass characteristic and find the -3dB points.

Min. insertion loss is ____________________

Low 3dB point is ____________________

Upper 3dB point is ____________________

Marker functions, automatic filter measurement.

Instructions	HP 8753D
Reset marker to OFF Use another marker tool to evaluate the filter. Discover the minimum insertion loss and the 3dB bandwidth automatically. Delta marker ensures measurement of -3dB with respect to the min insertion loss point. Use marker search to find the all of the data together.	[MARKER] {all OFF} [MARKER FCTN] {MKR SEARCH} {MAX} {Δ MODE MENU} {Δ REF = 1} Places the marker at the min. insertion loss point {WIDTH VALUE} -3dB {WIDTHS on}

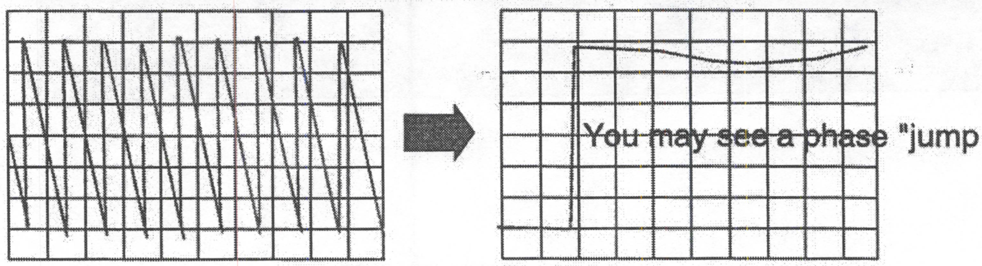
Min. insertion loss is ____________________

Low 3dB point is ____________________

Upper 3dB point is ____________________

Substitute electrical delay.

Instructions	HP 8753D
Reset marker to OFF	[MARKER] {all OFF} [FORMAT] {PHASE} [SCALE REF] {AUTO SCALE} if necessary [SCALE REF]
Adjust electrical delay until the "sawtooth" trace looks flat	{ELECTRICAL DELAY} [KNOB] cw until display looks "flat"



When you have substituted electrical length to balance the average length of the DUT you may see a display similar to to one above. If you feel offended by the jump in the display it may be corrected by an adjustment some phase offset.

What is the electrical delay? __________

Substitute electrical delay automatically.

Instructions	HP 8753D
Reset electrical delay to zero Observe the trace, the analyzer calculated the optimum delay for the trace. Read the substituted delay	[0] [X1] [MARKER] [KNOB] marker to screen center {MARKER FCTN} {MARKER -> DELAY} [SCALE REF] {ELECTRICAL DELAY}

Authoring Division Name: SSV File Name VNA_LAB.PRE

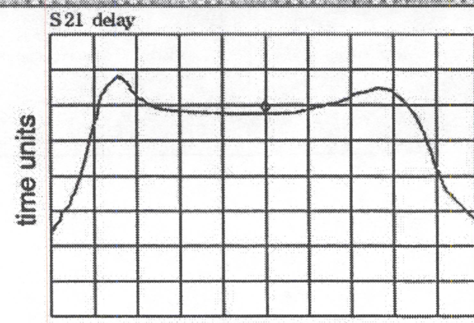
What is the electrical delay? ___________

This shold be close to your manual adjustment.

Vector Network Lab

Measure group delay

Instructions	HP 8753D
Reset electrical delay to zero Observe the trace, the analyzer now displays the derivative of the phase characteristic. Read the group delay delay using the marker	[0] [X1] [FORMAT] [DELAY]



Group delay has more physical significance than deviation from linear phase. Since an information signal has bandwidth it is the group delay distortion (deviation from flat or constant delay) which will determine the fidelity of the information signal. Each Fourier component will by subject to the delay at its frequency, so the transmitted signal will not be a replica, in the time domain, of the input signal.

What is the delay at the center ?_____

Does this seem reasonable?_____ does it seem OK for the physical device length?

Network Analyzer Amplifier Lab with HP 8714B

Microwave Fundamentals Training

Objectives

This lab is an excersize in planning and using the network analyzer.

FIRST: discover the calibrated output power range of the NWA. Use the supplied filter as a DUT.

THEN: figure out from the data the required range to test the amplifier to just beyond the 1dB compression point.

THEN: Do it!

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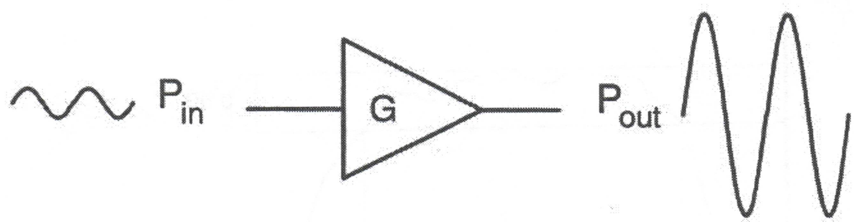
Before testing the active device, you may need to get to know the network analyzer, use the supplied filter as a DUT. The 8714 NWA is a vector NWA with simplified operation, we shall only do a transmission calibration. The measurement procedure for this measurement is relatively simple, the art of active device measurement is to get all the power levels correct, so once you feel comfortable with the analyzer spend some

Power Gain



$$G\,(dB) = 10\,Log\,\frac{P_{out}\,(mW)}{P_{in}\,(mW)} = P_{out}\,(dBm) - P_{in}\,(dBm)$$

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This simple definition of gain, will suffice since the source and load and DUT are nominaly 50ohms, we will assume they are exactly 50ohms. For information here are some more precise definitions.

Definitions

GAIN at a specific frequency.

Available Power Gain is the ratio:

Power available from output of netork to the power available from the source. (conjugate complex matching)

Insertion Gain is the ratio:

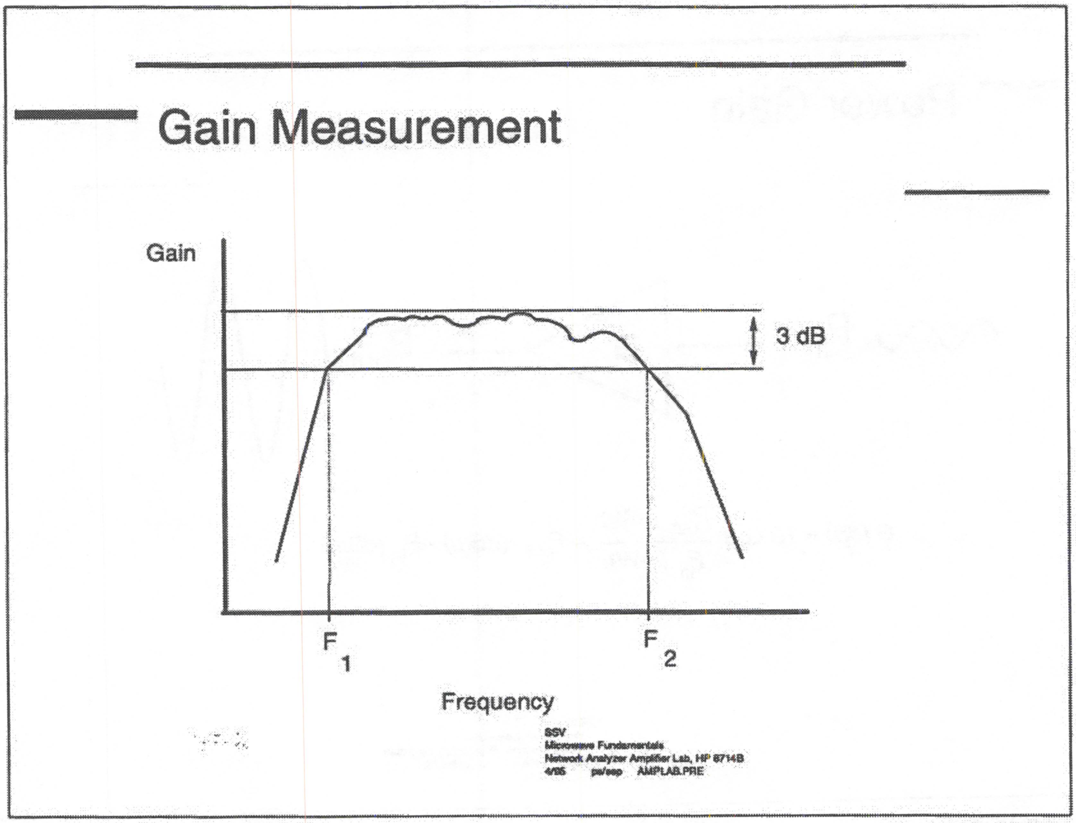
Power delivered to the load to the power delivered by the source to the load (the calibration step).

Power gain is the ratio:

Power delivered to the load by the network to the power delivered to the network by the source.

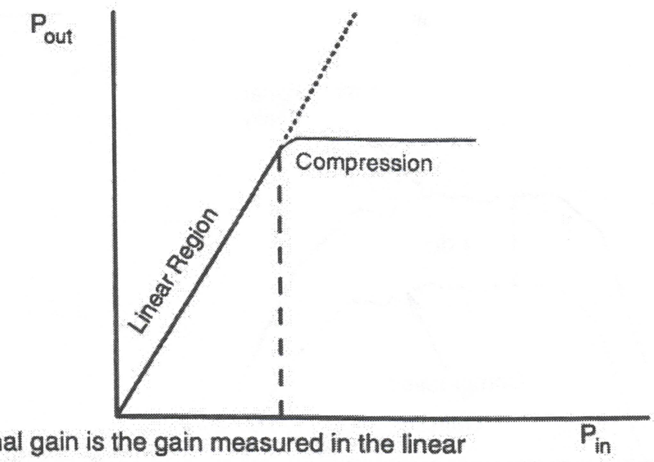
Transducer power gain is the ratio:

Power delivered to the load by the network to the power available from the source.



One of the desired pictures of the amplifier performance is the frequency response, gain vs. frequency at a constant drive power level. The 8714 analyzer does not have the low frequency performance to test for the lower 3dB point so we will fix the lower frequency at 1MHz. for convenience.

Amplifier Compression



Small signal gain is the gain measured in the linear region, well away from the compression point.

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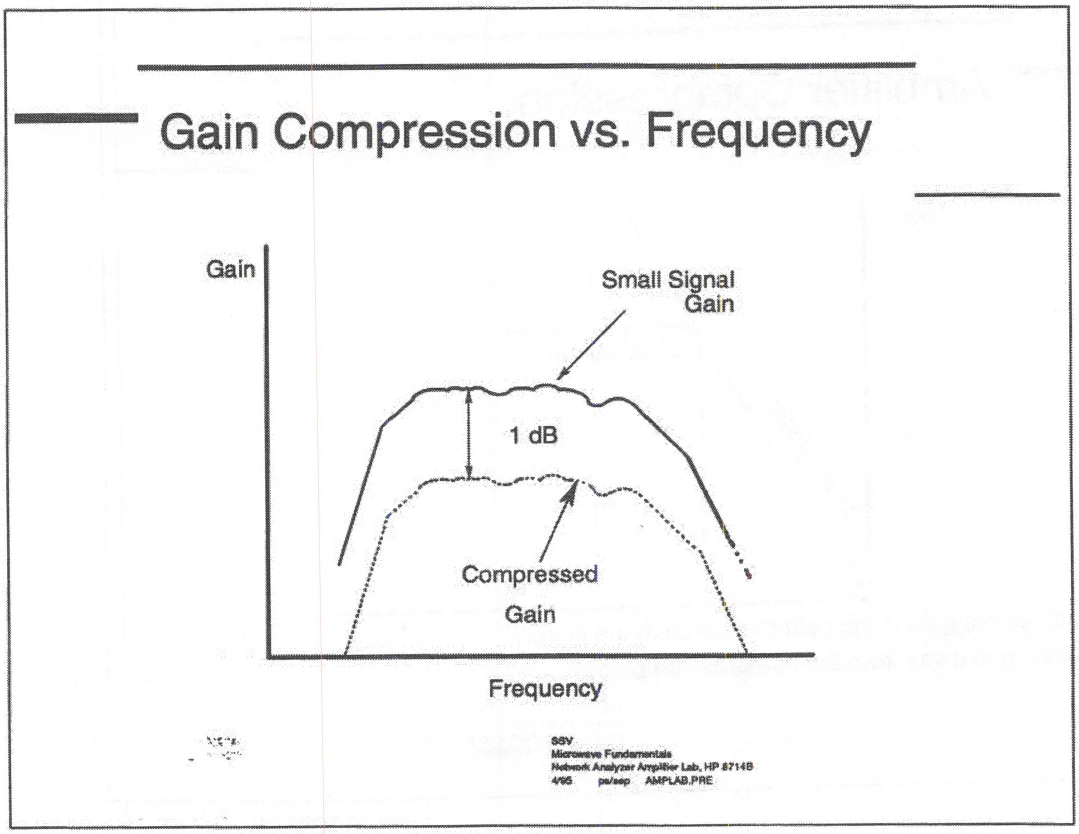
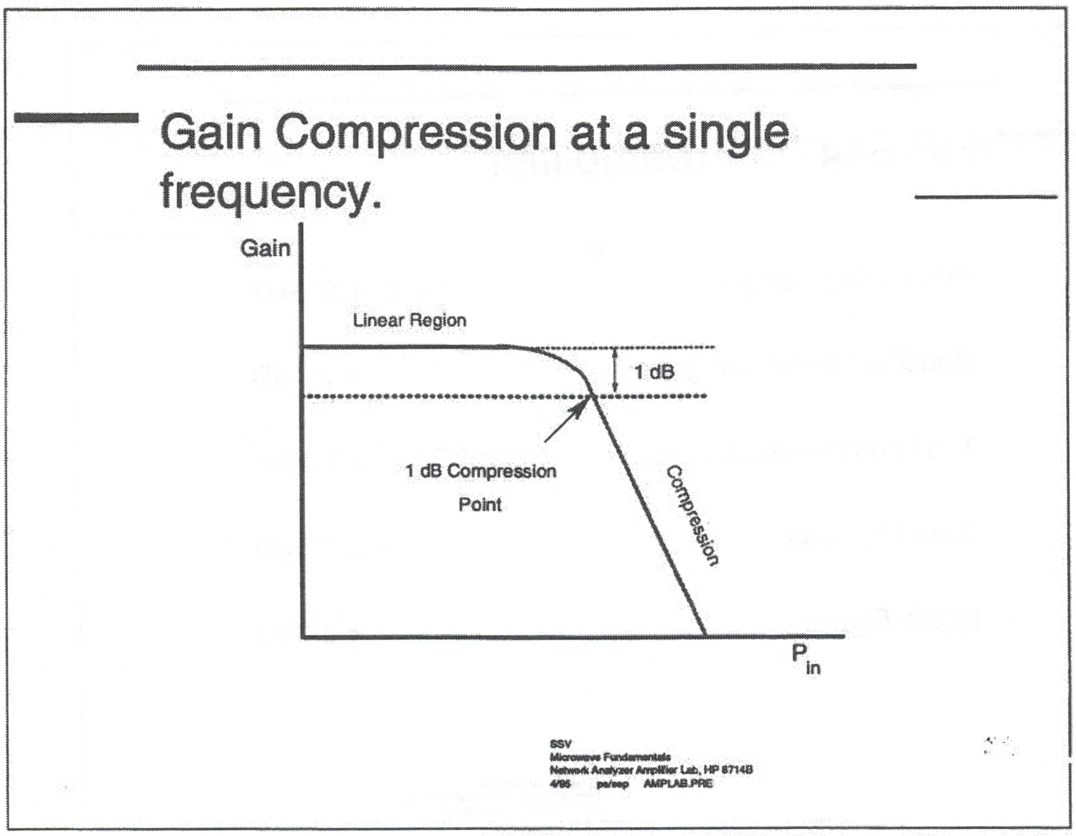
Another graph of amplifier performance is the output vs. input power at a constant frequency. The linear region although it looks straight will not be a perfect straight line, such an amplifier will generate harmonics even in the "small signal" region of the characteristic, but for this test we are interested in the point where the gain drops by 1dB, this is called the 1dB compression point.



If the small signal and compressed frequency response characteristics were plotted together then the the two graphs would be separated by 1dB only at the frequency at which we had set the state, but elsewhere the separation would probably not be 1dB. It may be more or less than that.



Another way of viewing the performance at a constant frequency is to plot gain vs. power input.

HP 8447D Preamplifier

Frequency Range:	.01 to 1.3 GHz
Specified minimum gain:	> 25 dB
1 dB compression point:	typical Po > + 7 dBm
Gain Flatness	< ± 1.5dB
Noise Figure	< 8.5dB

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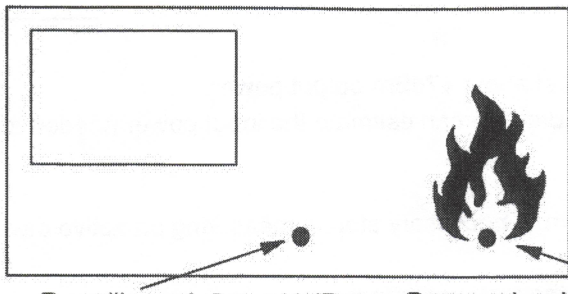
The 8447 amplifier is a preamplifier, this means it would be used in the first stage of a system, it has a moderately good noise figure and gain, so could be used at the front end of a signal analyzer system.

We shall be using these numbers to power budget our test system.

Power Budget for measurement



Po calibrated -5 to +10dBm
check this for yourself!

Damage level ≥ +20dBm
Analyzer Compression at +10dBm

Min power	
Max power	

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First use the supplied filter to get used to the 8714 functions, while you are doing this use the power control to discover the valid power range on your analyzer. Please note very carefully the other numbers on the above figure. The 8447 amplifier is not capable of damaging the analyzer but if you were testing another active device this would be a very important consideration. The output power of the 8447 may however exceed the compresion level for the analyzer.

We know the compression point is at about +7dBm output power.
We know the minimum gain is 25dB so we can estimate the input power needed to achieve compression.

We are power budgeting the system, a necessary step in measuring an active device.

1) To make sure we dont damage the test equipment.

2) To see if can stimulate the DUT over the needed power range.

3) To make sure the test equipment does not distort the measurement.

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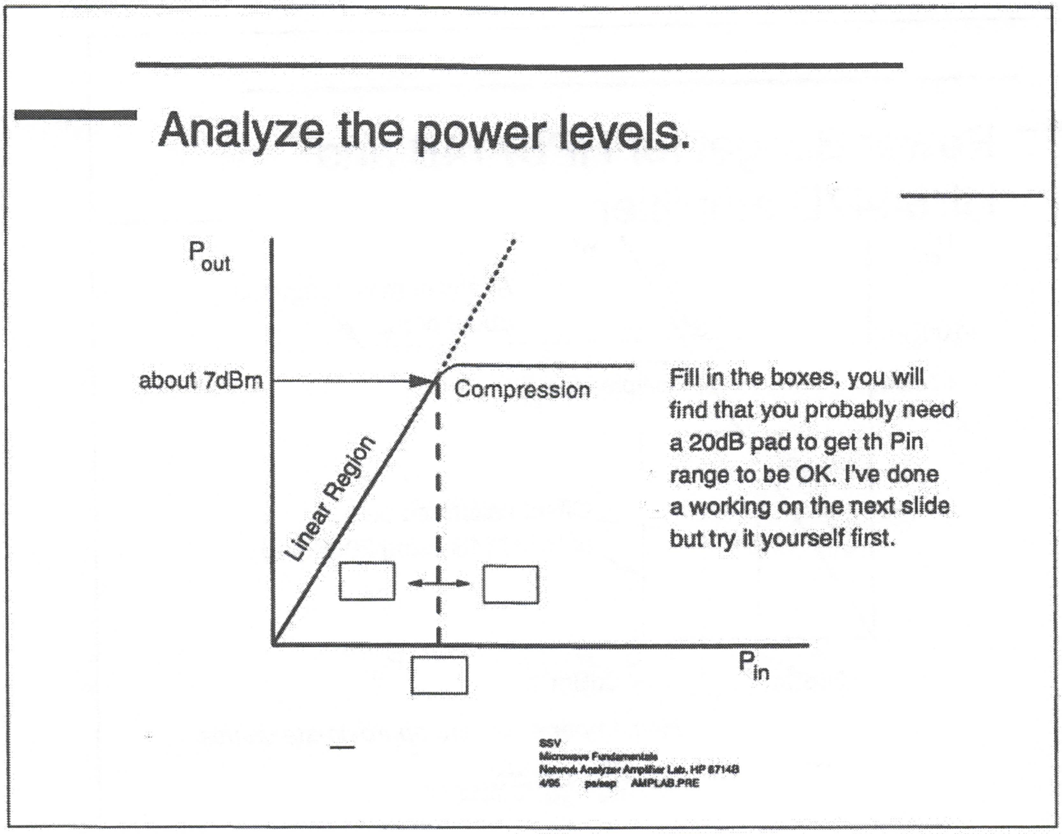
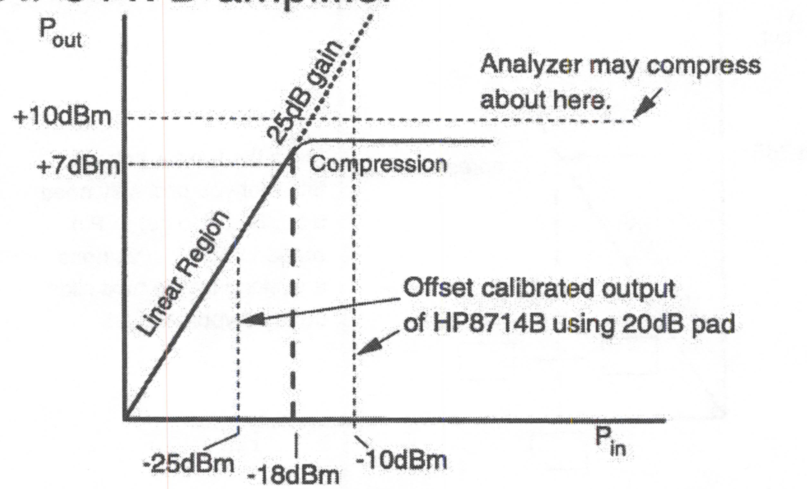
The next few pages are the very important planning stage of this task. Please dont rush but think about all the possibilities.



Remember that +7dBm is a minimum output power at compression.

Power Budget for HP8714B and HP8447D amplifier



Remember these are approximate values.

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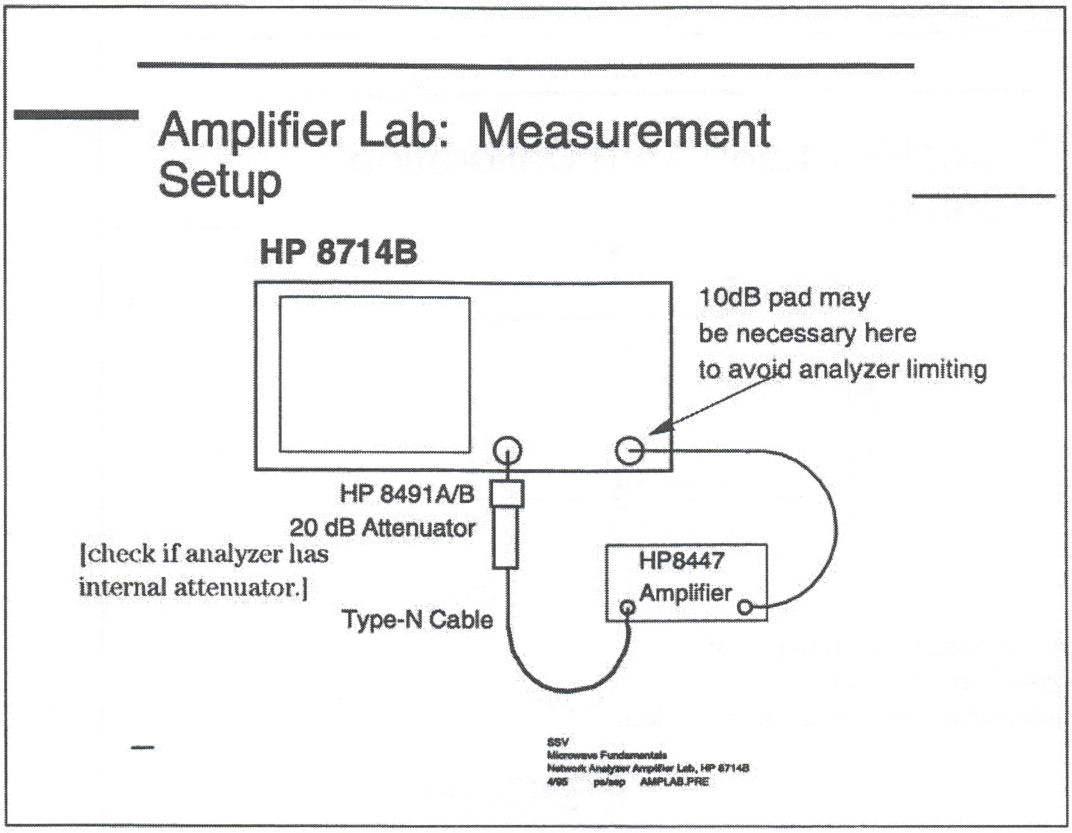
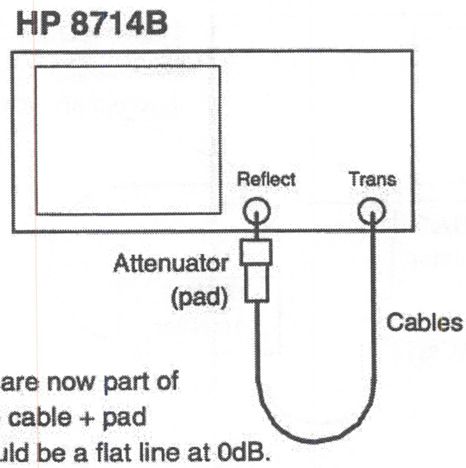
You will already have discovered that the output power of the analyzer is too high to test the 8447 amplifier over the indicated range. (some 8714's have the internal attenuator option)



Since the +7dBm spec is a minimum, you may have a unit which is very close to or exceeds +10dBm w

Amplifier Lab: Thru Calibration Setup



The pad and cables are now part of the NWA. Check the cable + pad measurement it should be a flat line at 0dB.

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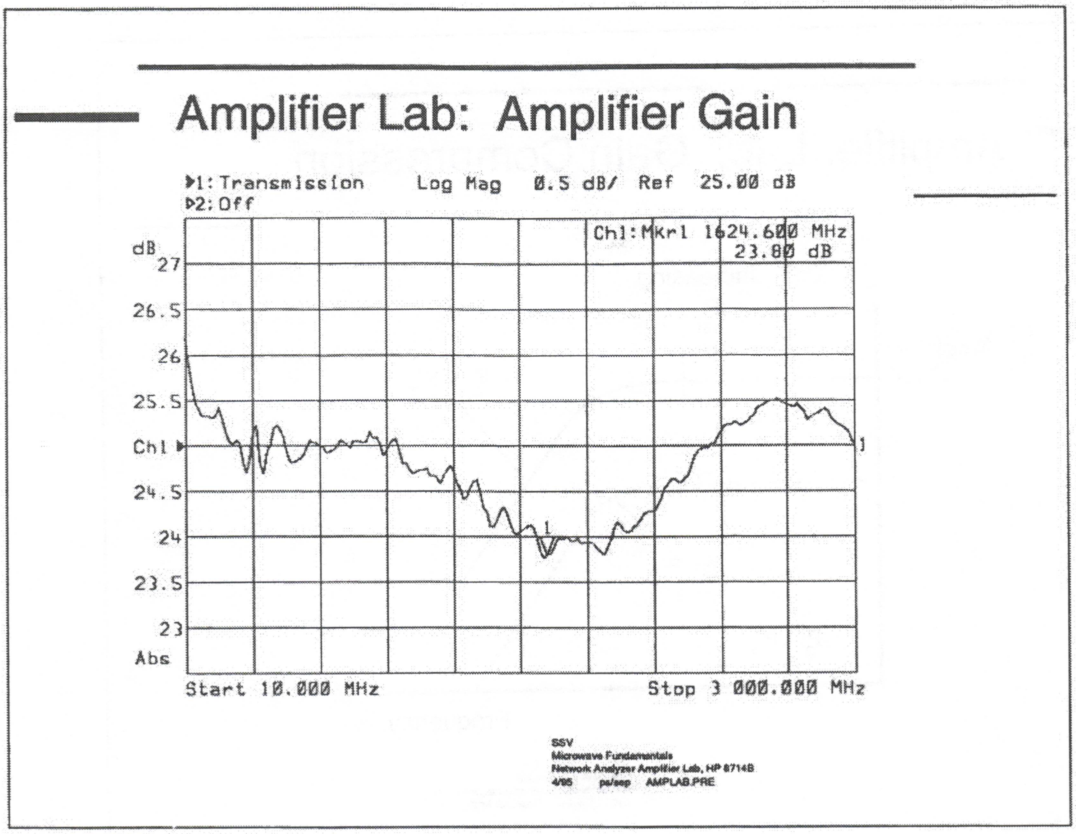
The attenuator(s), the cables and the bullet (N(f) to N(f) adapter) are part of the calibration path, we shall ignore the contribution of the bullet which will not be present in the measurement path. The amplifier with two N(f) connectors is called a *non insertable* device, and as such needs the adapter for the calibration stage.

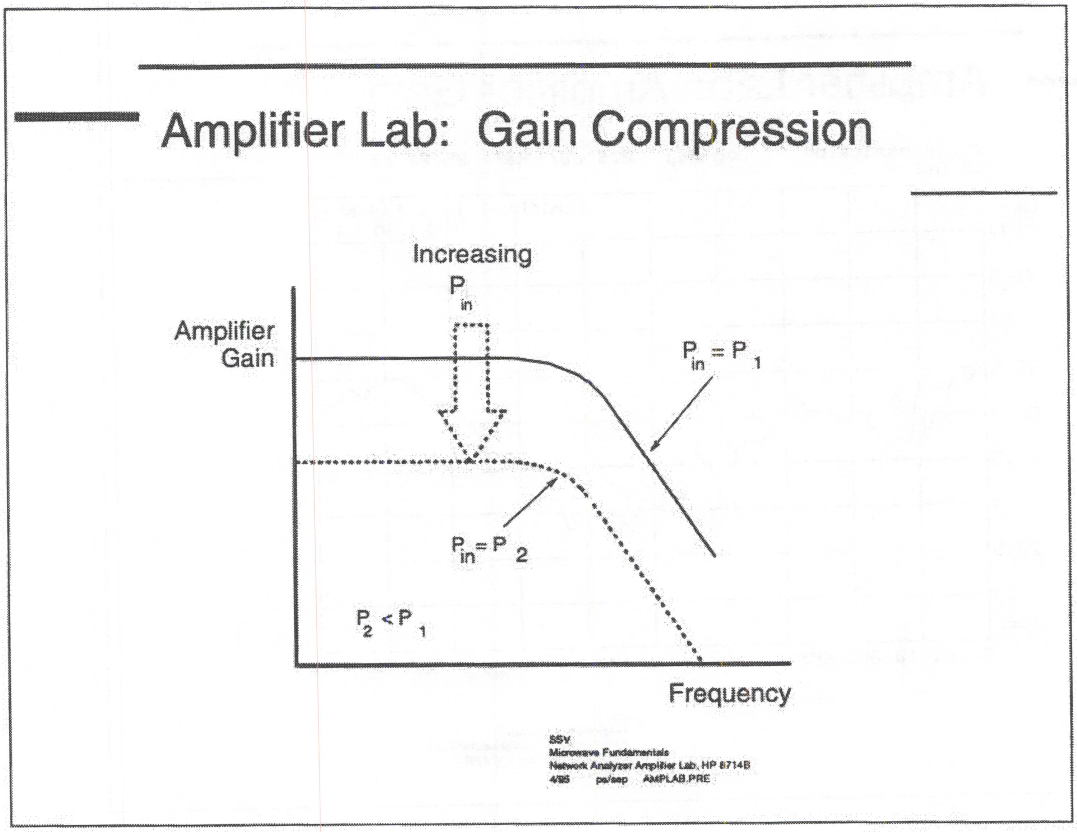
1) Adjust the power to the minimum, to ensure small signal conditions when the amplifier is attached.
2) The recommended frequency range ig 1MHz to 2GHz.
3) Select *transmission* measurement and follow the calibration instructions.
4) Check your calibration while the thru connection is there, you should get a flat line at 0dB. If you did an autoscale then with a small dB/div you will see a noisy trace but it will be centered around 0dB.



At last we can measure! The above trace was taken from another amplifier type but is typical of the plot you should get.

Check that over the 1.3GHz range the gain is above 25dB.

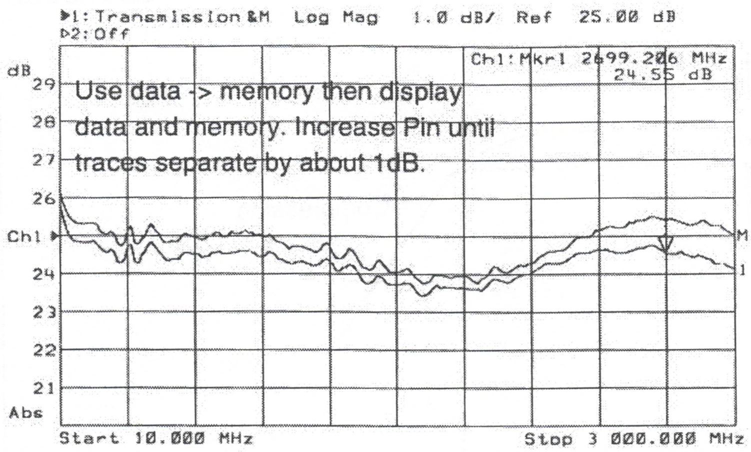
What do you get on average?	25dB	_____
	26dB	_____
	27dB	_____
	28dB	_____



Now activate power, and increase the power with the knob or the step key, puase after each change to allow the NWA to update the display.

Did you notice a difference in the trace as you did this?

Amplifier Lab: Gain Compression vs. Frequency



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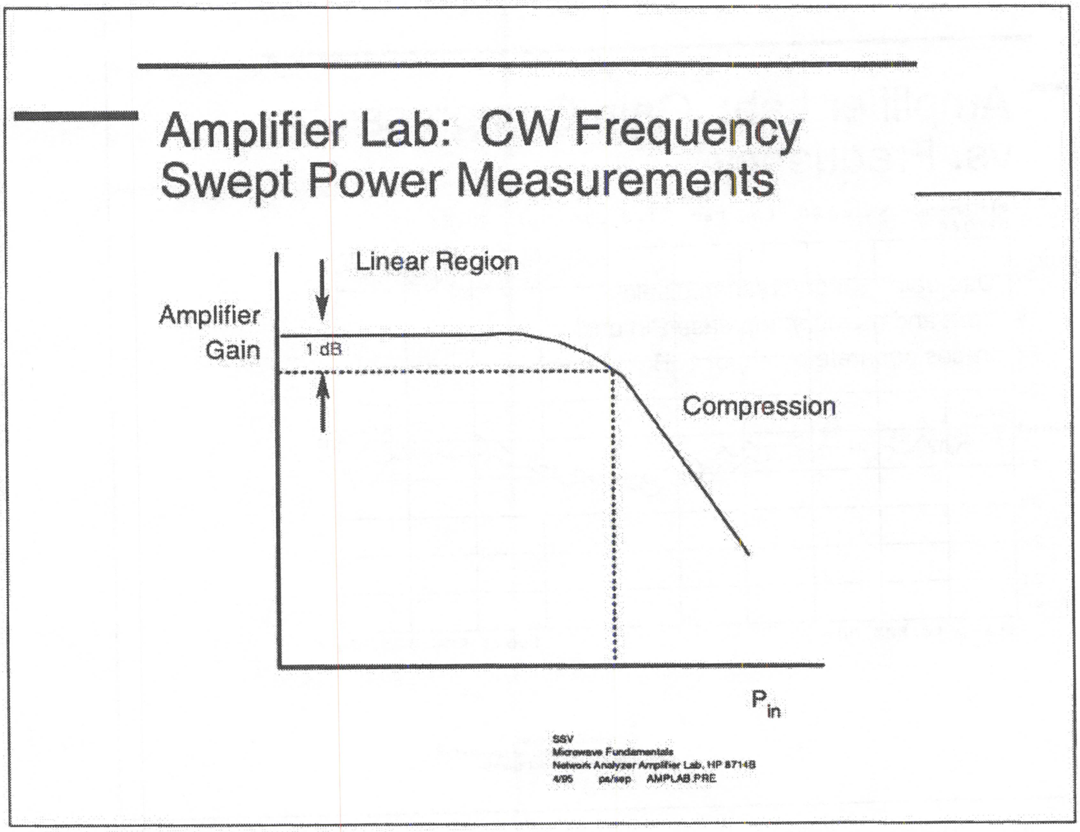
To be sure of the change do this:

1) Reset the power to the minimum (small signal condition)
2) Fine the display menu, press DATA > MEM then DATA & MEM
You now have two traces, the live trace superimposed on the memory trace.
3) Now increase the power as before until there is about 1dB difference between the traces.
This works best if the dB/div is 1dB.

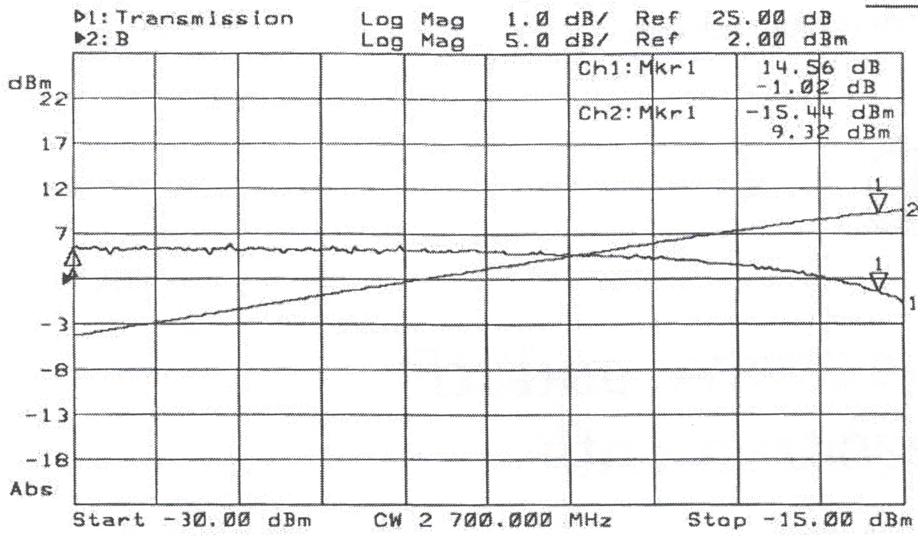
As the 1dB compression point is different for different frequencies a better way to measure this would be at a single frequency.



Single frequency power-sweep

Find under the sweep control the power sweep key, if this is activated the analyzer will go to the CW mode at the center frequency. You can change this frequency at any time by pressing CW and entering the wanted frequency. Set the power start and stop so that the power sweep is sweeping from the minimum power to the maximum power.

Amplifier Lab: CW Gain Compression vs. Input Power



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The above trace shows the measurement of swept power input vs. gain on CH 1 and absolute power on CH2. The 8714 uses a broadband detector and of course does not know about any external attenuators you may have used and so will indicate the power at the inupt and output ports, not necessarily at the amplifier.

You may like to note the small signal bandwidth and gain information for the noise figure lab.

Spectrum Analyzer Lab.

Microwave and RF measurements

Objectives

- 1. To interpret the display and note some important parameters of a swept tuned spectrum analyzer.
- 2. To use a spectrum analyzer in its fundamental operations of tune, zoom and measure.
- 3. To investigate the range of signal levels measurable with a swept-tuned spectrum analyzer.

Spectrum Analyzer Lab

Some 8594E Specs.

- 8594E Brief Specifications.

- Freq range 9kHz - 2.9GHz dc coupled
  100kHz - 2.9GHz ac coupled

- Freq. reference accuracy $\pm 2 \times 10^{-6}$ /year

- Freq readout accuracy:
  ±(f readout × freq. ref. error + span accuracy + 1% span + 20% RBW +100 Hz × N)
  (N = 1 for 8594E)

Specifications describe warrented performance over the temperature range 0°C to 55°C (unless otherwise noted). The spectrum analyzer will meet its specifications after 2 hours of storage at constant temperature , within the operating temperature range, 30 minutes after the CAL frequency and CAL amplitude routines have been run.

Prepare the equipment

- Preset the spectrum analyzer PRESET
- Set up the signal generator

Initial Instrument Settings:

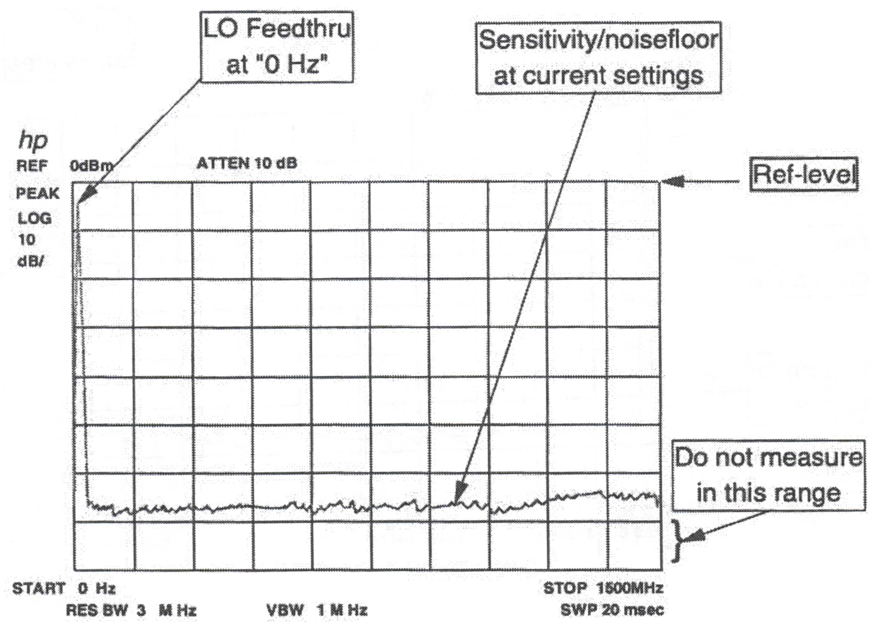
1. Connect the equipment:

2. Set controls as follows:
HP 8594E Spectrum Analyzer:
LINE switch to "1" (pressed in)

Press INSTRUMENT STATE PRESET] button.

NB. *the screens on the following pages are for information only, they do not necessarily represent the screens you will get in all details.*

hp Spectrum Analyzer Display 859X series

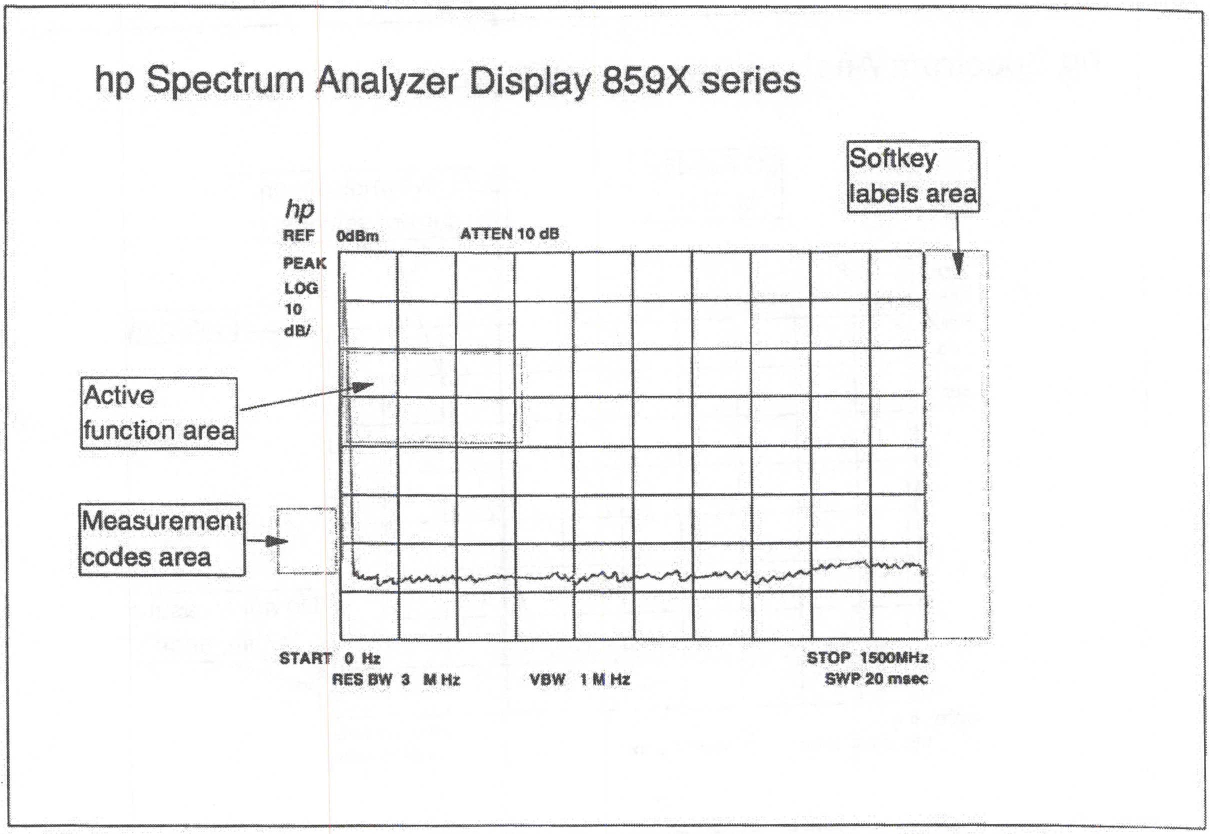


Press the green [PRESET] key. This sets the analyzer to a known state. This is a good starting point for most measurements. If you have difficulty later on making a measurement, you can start over by using this key again.

If no signal is applied, the spectrum analyzer display should be similar to the one pictured above.

On the left of the CRT will be the "LO feedthru" which is always present even with no input to the analyzer. This response is at 0 Hz, and care should be taken not to confuse this with a signal to be measured. This is a feature of all swept analyzers and is present where the LO is momentarily at IF.

Be sure to check the valid measurement range (vertically) of your analyzer. This particular analyzer is not specified for measurement in the lowest division at 10dB/div scale setting. This means that in the 10dB/div mode the amplitude measurement may only be made over the range from the ref-level to 70dB below the ref-level.



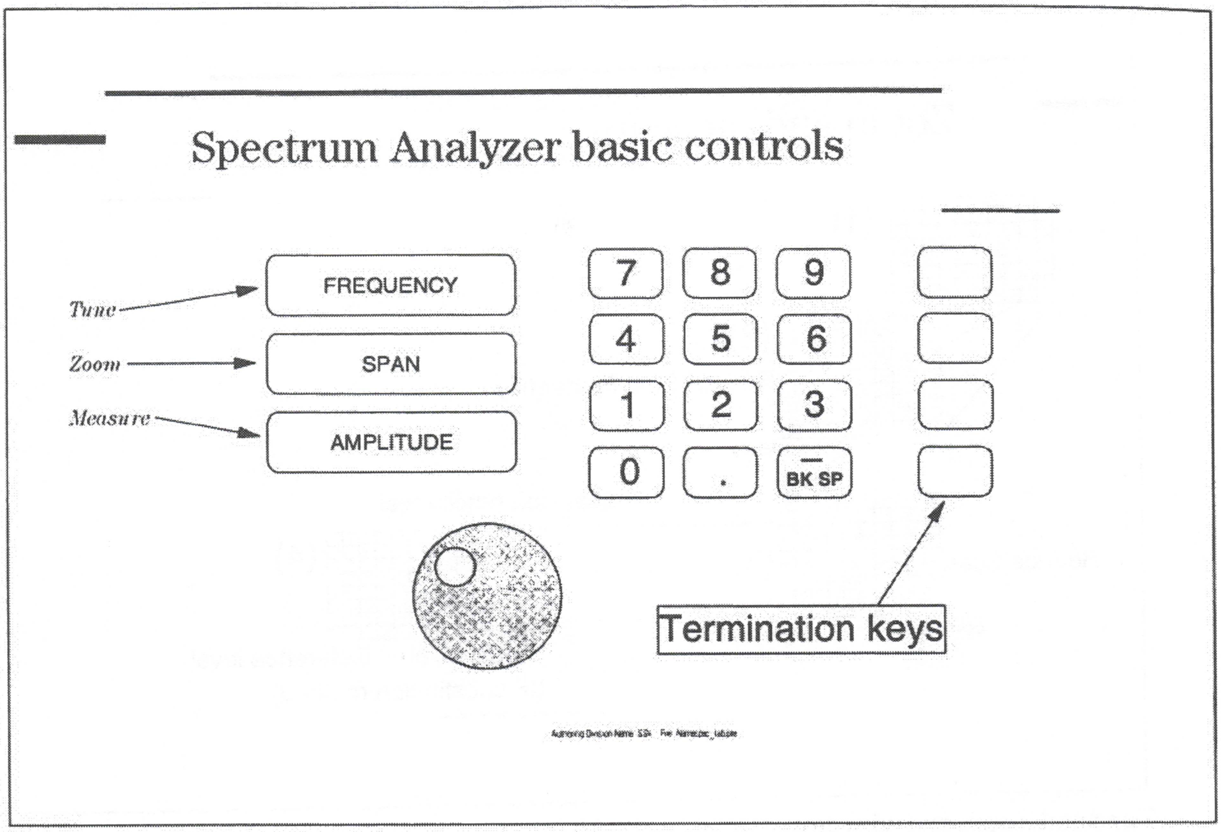
Observe the screen for information, a few of the areas are shown here.

The *Active Function Area* is very important. When a function is displayed here it is the function that can be modified by the :-

* keypad (remember to terminate with a unit)
* knob
* up/down keys

Measurement codes: Sweep, Trace and Trigger Modes

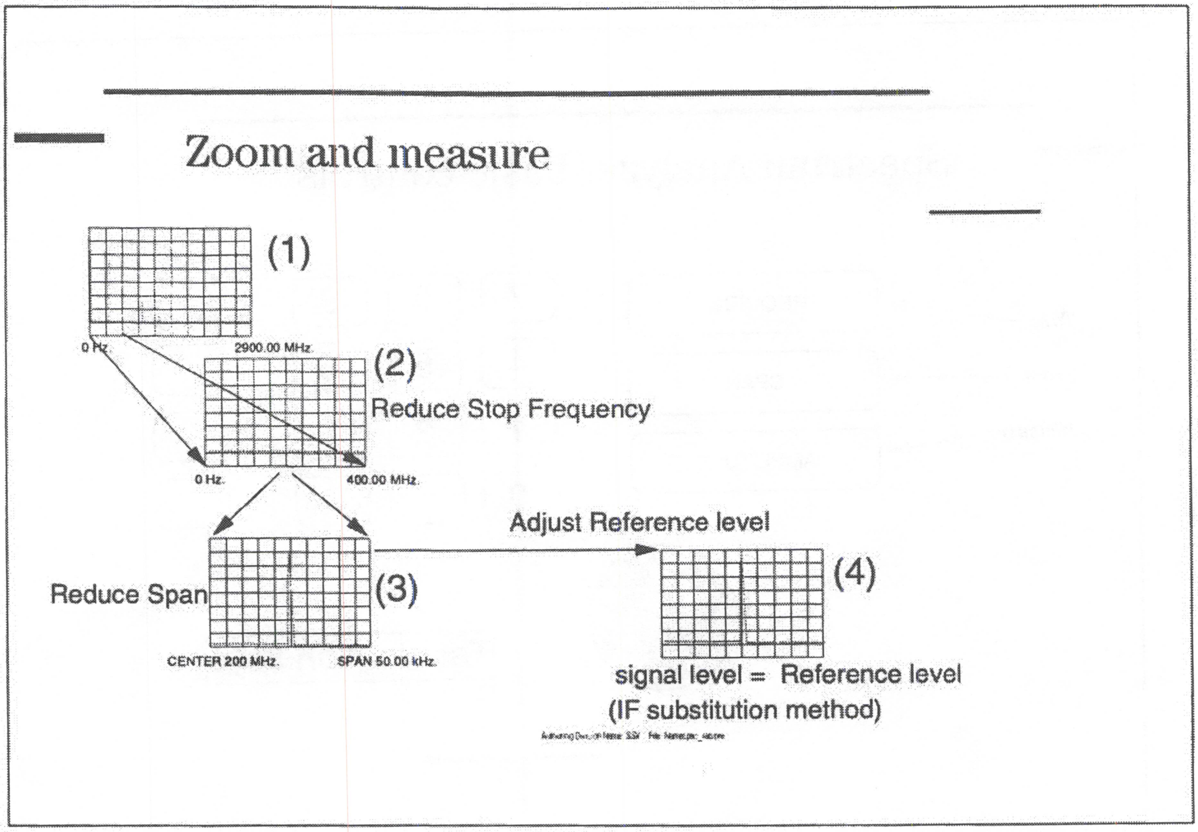
TRACE	TRIGGER	SWEEP
W = Clear write(A/B/C)	F = Free run	C = Continuous
M = Max. hold(A/B)	L = Line	S = Single
V = View(A/B/C)	V = Video	
S = Store blank(A/B/C)	E = External	
M = Minimum hold(C)		



This lab will give you some experience using a superheterodyne swept-tuned spectrum analyzer.

The HP 859XE is typical of this type of analyzer and it's fundamental operation, tune, zoom, and measure, is common to all spectrum analyzers of this type.

Try to use just these basic controls and the marker for the moment. If you are already familiar with this please sit back and allow your lab partner to experiment with these controls.



Tune and Zoom and Measure

TUNE, ZOOM and MEASURE describes the process of measuring the required signal using only the basic controls.

Try the procedure with the calibrator signal hooked up to the SA input.

Connect the calibrator signal to the input of the analyzer. This is a -20dBm signal at 300 MHz, it is rich in harmonics so you will see responses at 600, 900 etc. By using the basic controls that are accessible from the FREQUENCY, SPAN and AMPLITUDE keys. Try to get a picture like the next slide.

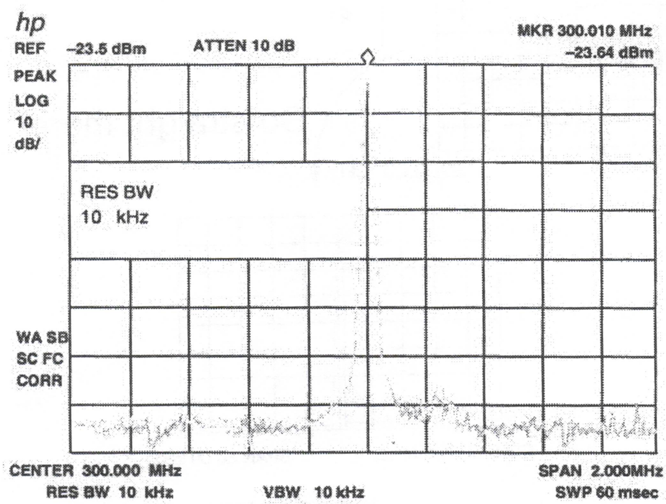
(1) Preset state:

(2) adjust the STOP frequency: Note that the corresponding CENTER and SPAN may be viewed just by activating CENTER, toggle back to STOP to continue adjusting. Note the RBW , VBW and Sweep time at each step.

(3) Adjust SPAN: You may have to reposition the signal at the center of the display by adjusting CENTER FREQ.

(4) Adjust the REF. LEVEL to measure the signal.

Zoom to cal signal

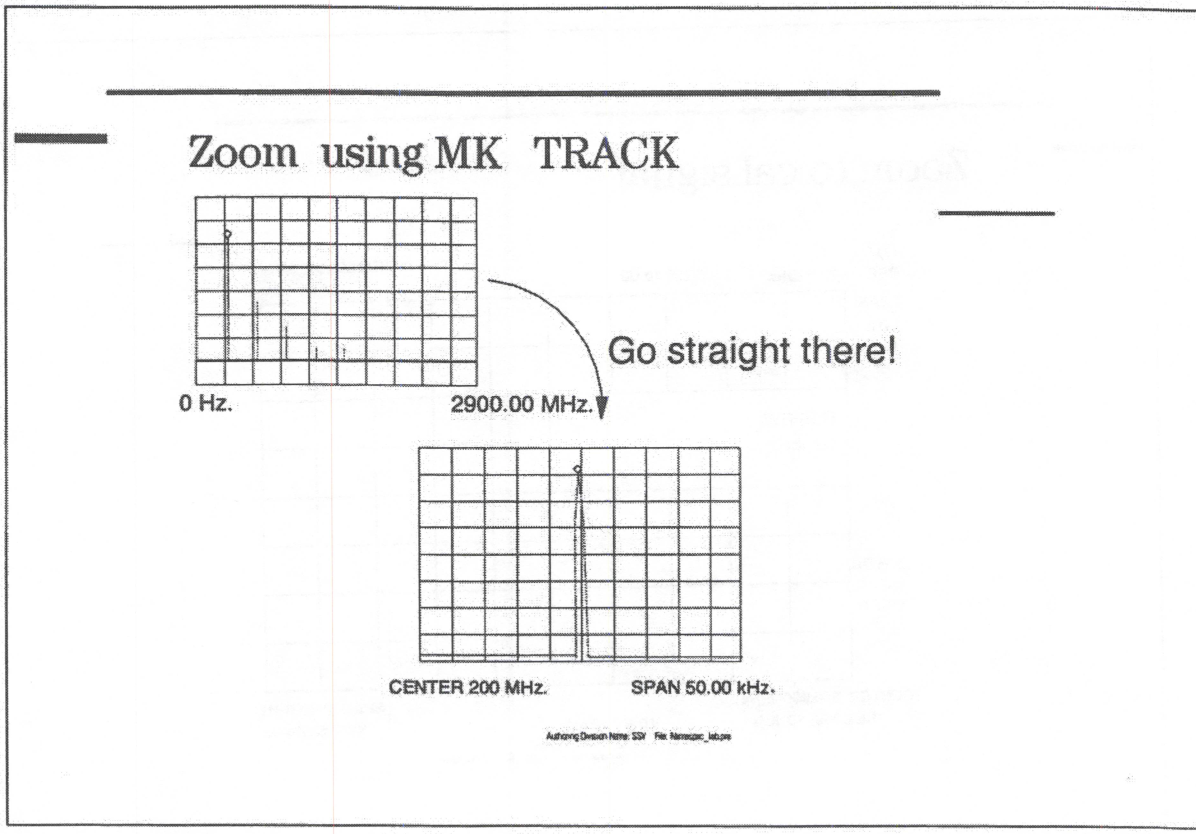


Keep using the CENTER/SPAN and START/STOP to achieve a 400 MHz then a 50 kHz. span about the 300MHz calibration signal

Note the values in the table.

Span	Resolution BW	Video BW	Sweep time
FULL			
400 MHz			
50 kHz			

Notice how the RBW ,VBW and sweep time are adjusted as the span changes.



By using the marker track function you can go directly to the wanted signal with the desired span.

The Mk Trak is accessed under the MKR FCN hardkey. Try to do this *without* cookbook instructions.

NB. 1) make sure you have the correct signal selected before activating marker track.
2) when you have the desired display, *switch off* marker track.

CENTER FREQUENCY STEP

While the calibrator is connected let us try another useful firmware feature.

With the marker on the desired signal use MKR -> CF STEP, this will put the marker frequency into the register that controls the operation of the up and down arrow keys. Alternatively you could enter 300 MHz into CF STEP from the FREQUENCY menu.

Use the up/down keys to explore the harmonics of the calibrator signal.

Accuracy/ Uncertainty

Put in your values, think about the uncertainty of each reading. The information below taken from the data sheet should help.

Frequency MHz	Level dBm	Uncertainty
300		±(2+.4dB)
600		± 4.5dB
900		
1,200		
1,500		
1,800		
2,100		
2,400		
2,700		

HP 8594E: **Frequency Response Specifications.**

9 kHz. to 2.9 GHz. ± 1.5dB Absolute. ± 1.0 Relative

Display Scale Fidelity.

Log Maximum Cumulitive:

0 - 70 dB from reference level

3 kHz to 3 MHz RBW ~~±(0.3 +~~ 0.01 × dB from ref-level)

Log Incremental Accuracy: ± 0.4dB/4dB 5

0 to – 60 dB from ~~reference level~~ 30 3.0 ~~2.0dB~~

Calibrator Output.

Amplitude – 20 dBm ± 0.4 dB

Try to figure out the absolute uncertainty for a few of the harmonics.

Other factors, which can affect uncertainty:

Mismatch. (input match can change with attenuator change, but poor at 0dB setting.)

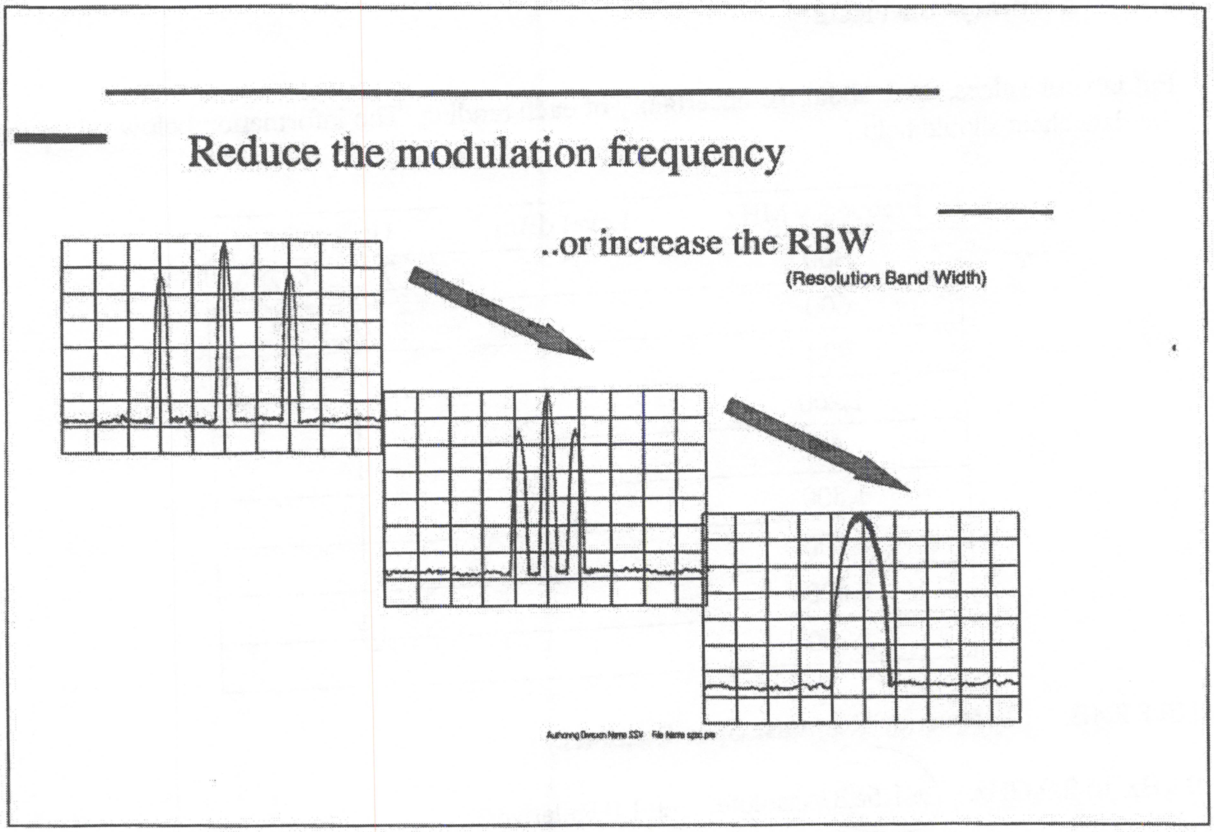
Changes of state from calibration.

RBW.

Input Attenuator frequency response.

Ref. Level.

Scale Factor.



Connect the signal generator and set 50% modulation AM on the signal generator SIN 10KHz internal.

On the spectrum analyzer, you should now see two additional signals.Write a few words of interpretation of what you now see on the display.

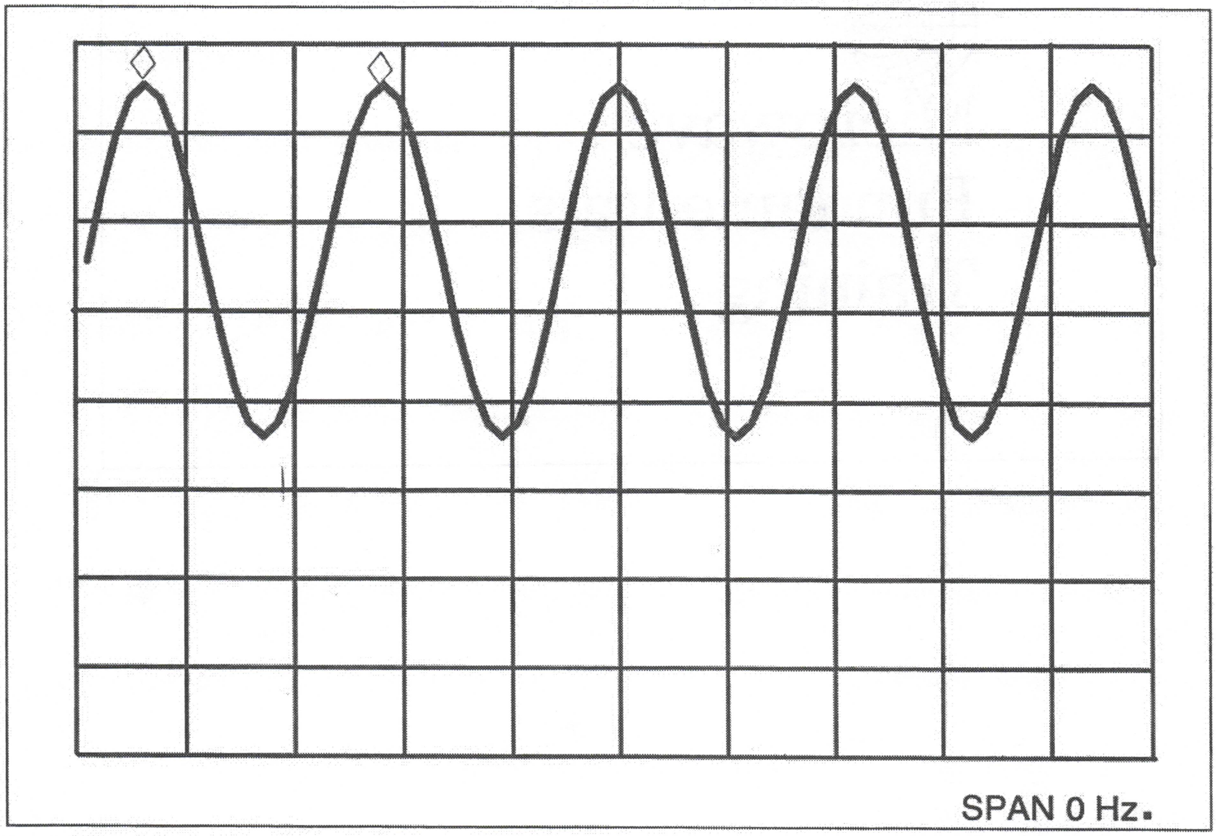
As a final step in your exploration of tune and zoom, look at what other spectrum analyzer parameters besides span have a significant impact on frequency resolution.

Start decreasing the modulating signal frequency. Watch what happens on the spectrum analyzer display as you reduce the modulating signal frequency to about 3 kHz. At this point you are about to lose sight of the sidebands because there is not enough frequency resolution.

Write a few words of explanation as to what is affecting frequency resolution now. Are the amplitude changes what you would expect? Remember with 50% modulation the sidebands are –12dBc. (Should be about .5dB more than the carrier alone.)

f_mod	Amplitude of "carrier"
10 kHz	
3 kHz	
0.5 kHz	

The last experiment was an example of narrowband (NB) and broadband (BB) signals. As soon as more than one frequency component is similtaneously received, the receiver is in the broadband condition, so the terms BB and NB applied to a receiver are relative to the receiver bandwidth. If there were a number of closely spaced signals in the spectrum, closer than the bandwidth, then the receiver (spectrum analyzer) is measuring in the BB condition. Furthermore if the RBW is increased the level of the displayed signal will increase as more components are "received". If the closely spaced signals are harmonically related then the signals are correlated and will add as voltages. The increase will be as 20log(BW).



ZERO SPAN

Try to achieve a time domain picture of the modulating signal.

- BB mode (RBW >> f_mod)
- Adjust signal to be in first division from ref. level
- Amplitude LIN.
- SPAN 0Hz.
- Trigger; Video. you can adjust this like a scope trigger.
- Try the markers

Noise Figure Lab

Microwave Fundamentals Training

Noise Figure Lab

LAB: Introduction to Noise Figure

- In this lab we shall use microwave power measurements to calculate noise figure.
- The relationship between power, temperature and bandwidth has been stated as:

$$P = kTB \;=\; -174\text{dBm/Hz} \;\; (\text{at } T = 290\text{K})$$

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290K is about 17°C or 62.6°F this is called room temperature, rather a cool lab environment! For sitting jobs most Americans would prefer 70°F which is about 294K.

This is about 1.4% higher and would represent 0.06dB increase in power/Hz.

Power Sensors:

The 8484A and 8481D are high sensitivity power sensors,
100pW to 10mW (-20dBm to -70dBm)

Many of the measurements in this lab are at, *or just below, the specified range of the power sensor*, this means that you will have to be very careful in handling the sensor and to frequently ZERO the meter.

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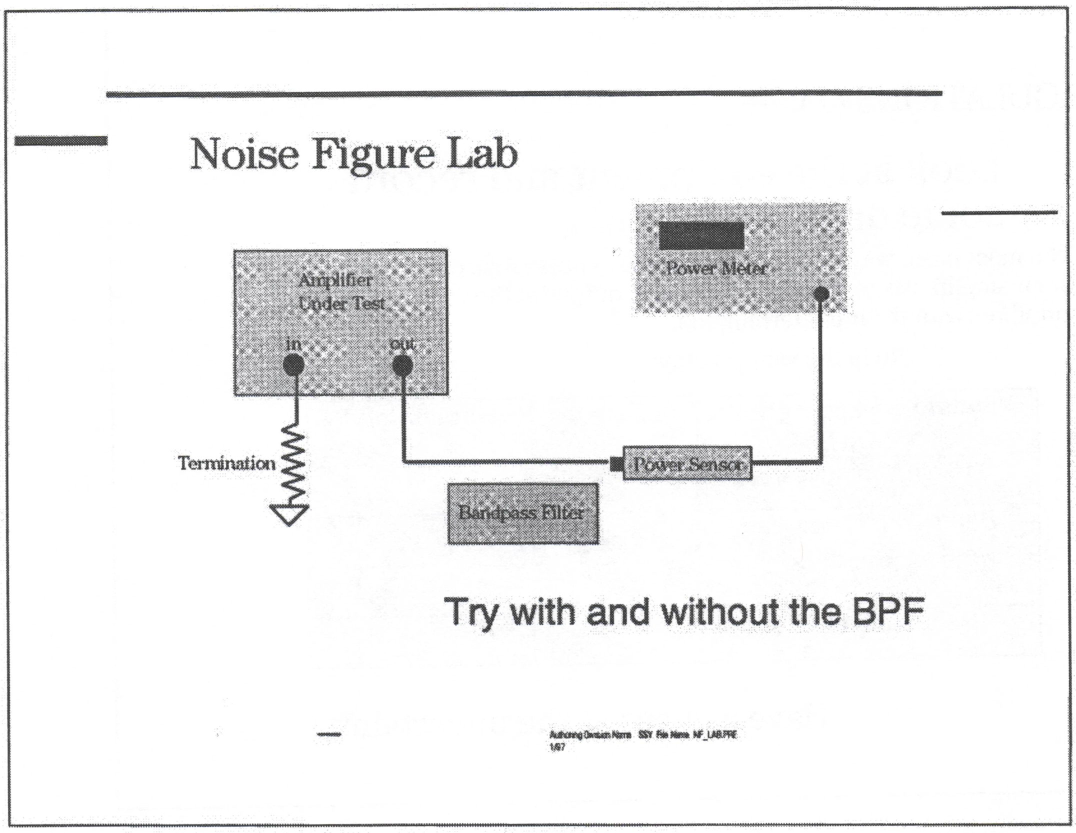
The precision 30dB pad is necessary for calibration, because the power the 1 mW reference is too high for this sensor. The 437B power meter is able to recognize the type of sensor attached, so it expects the 30dB pad to be present during the cal. sequence. ie. a -60dBm calibration source.



Noise Figure: Basic method using a power meter

Calibrate and Zero the Power meter:

NB the 8484 Sensor has a measurement range -70dBm to -20dBm, this lab experiment will use the sensor at the bottom of its range. Please keep zeroing to ensure repeatible results.

The termination at the input of the amplifier will probably not be needed if there are no really high signals in the lab environment. (eg. a broadcast transmitter next door)
You may connect the noise source as a termination, make sure it is OFF!

CALCULATIONS (1):

Look at the equipment and record some data.

The most basic way to measure (estimate) noise figure of an amplifier is to measure the power output of the amplifier with the input terminated.

Write in the values below.

What do we know about our DUT?	Parameter	Uncertainty?
Gain of amplifier		
Bandwidth of amplifier		
Bandwidth of sensor		
Bandwidth of Filter		

Have a guess at the uncertainty!

The first part of this Lab is to observe! Please write in the table any data you can find out about the device to be tested.

Make a guess about the uncertainty if you can.

CALCULATIONS (2): NO Band pass filter

Based on this information what should be the noise power output of the amplifier if it adds no noise of its own?

Amplifier ***without*** BPF	dB value
kT (dBm)	-174
Gain	
Limiting bandwidth expressed in dB*	
Add them up	

* what bandwidth limits the noise output?
write it down as 10.log(bandwidth in Hz)
e.g. 1MHz ~ 60dB

This is a simple calculation to find the noise output of an amplifier with the attributes you have just written down.

Remember that because the total power output would be

kT X Bandwidth X Gain; if powers were in linear (Watts) terms,

then it is valid to Add the dB's for Gain and Bandwidth to the input power density kT.
ie.
10log (gain factor) + 10log (bandwidth Hz) + power density at the input dBm/Hz = Power out dBm./BW

dont confuse dB's with power, adding dB's to dBm's is equivalent to multiplying a (unitless) factor by the power in watts or mW.

CALCULATIONS (3):

Recalculate with Bandpass filter.

Amplifier ***with*** BPF	dB value
kT (dBm)	–174
Gain	
Limiting bandwidth expressed in dB	
Add them up	

This power may be below the published minimum power of the sensor by about 10dB. Go ahead and measure, remember to ZERO again.

This time use the BW of the bandpass filter in the same calculation. This will be a much lower power most probably lower than the specification limit of the sensor.

Noise Figure Lab

Now measure and compare with your calculations.

Noise Measurements		Noise Calculations		Noise Figure
	A		B	(A - B)
Power *measured:* no BPF		Power *calculated:* no BPF from previous page		
Power *measured:* with BPF		Power *calculated:* with BPF from previous page		

Remember: keep zeroing at each stage of the measurement.

Now Measure

In the preceding experiment we made some assumptions.

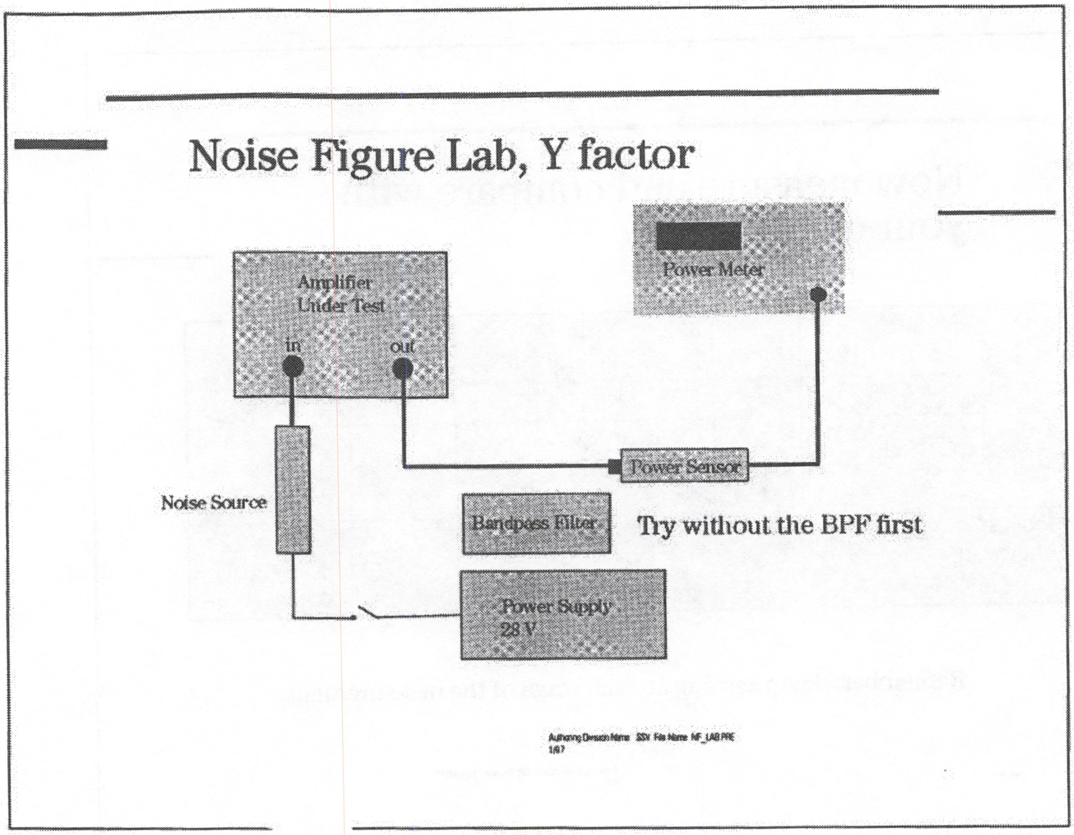
Amplifier gain was not measured, we assumed a nominal value.

The amplifier bandwidth was also nominal.

In the measurement with the filter the power meter was close to or below its specified range.

The gain of the amplifier may have considerable slope, this and the rolloff of its passband would mean we have a very rough measure of noise figure. The bandwidth we need is the "equivalent noise bandwidth" ENB, that is the "brickwall" bandwidth of a device that would pass the same noise as the device under test. Accurate measurement of the ENB of a device is not practical so an alternative method is used. This is known as the Y factor method which involves switching a standard noise source between ON and OFF and measuring noise change during this process. This removes the need to know the gain and ENB separately.

Perhaps you remember the approximate gain and bandwidth from the network analyzer lab. We may know the 3dB bandwidth but not the ENB.



Noise Figure: Y factor method using a power meter

Calibrate and Zero the Power meter
Try this first without the BPF, if you have time insert the BPF and re-measure.
NB the 8484/8481D Sensor has a measurement range -70dBm to -20dBm, when using the BPF the sensor will measure at the bottom of, or below its published range. Please keep zeroing to ensure repeatible results.
Measure power with P

The advantage of this procedure is that we need no knowledge of the device gain or bandwidth. If no bandpass filter is used, our result is the average noise figure over the frequency range of the amplifier. If the filter had been used it would have given a measurement of noise figure over the passband of the filter wherever it was centered, however the filter parameters would not be needed to compute themeasurement.

Measure and calculate.

Measure power reading with source OFF	
N1	dBm

Measure power reading with source ON	
N2	dBm

Calculate Noise Figure	
Y(linear) = 10^(N2-N1)/10 =	
Y - 1 =	
noise figure = ENR-10log(Y - 1) =	

These measurements will be about 10dB apart.

Since Y= N2/N1 when N is in linear (Watt) terms.

We must convert them to linear,

$$Y(\text{linear}) = 10^{(N2 - N1)/10}$$

then substitute this Y in the equation:-

$$NF = ENR - 10\log(Y-1)$$

A scientific calculator is helpful here.

Summary of results

Basic measurement of power

NF Without filter: ____ dB

NF With filter: ____ dB

Using Y factor measurement

NF Without filter: ____ dB

NF With filter: ____ dB

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Comments on methods

Method	Comment
Basic-No BPF	Large uncertainties: ENB of amplifier probably much larger than 3db BW. Power reading midrange: good. Gain of amplifier was nominal.
Basic-with BPF	This reduced the uncertainty due to BW, ENB about 1.2 times 3dB BW of filter. Power reading at very low range: poor. Gain of amplifier nominal.
Y -No BPF	Uncercainties of gain and BW eliminated. NF measured was an *average* over the *unspecified* BW of the amplifier. Power reading midrange: good.
Y -with BPF	Uncercainties of gain and BW eliminated. NF measured was an average over the filter band. Power reading at very low range: poor.

If the filters supplied are 10MHz then in all cases the power measured through this especially with the noise sourse off, or with no noise source, will be on the borderline of measurability.

However the Y factor method does give us a way of *not* needing knowledge of the DUT gain and ENR> (Equivalent Noise Bandwidth)

The Y factor technique is implicit to noise measuring instruments and many systems.